MULTIMODAL INTEGRATION IN TRANSIT SYSTEM BASED ON CBD ACCESSIBILITY: THE CASE OF ANKARA

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CITY PLANNING IN CITY AND REGIONAL PLANNING

JUNE 2020

Approval of the thesis:

MULTIMODAL INTEGRATION IN TRANSIT SYSTEM BASED ON CBD ACCESSIBILITY: THE CASE OF ANKARA

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ABSTRACT

MULTIMODAL INTEGRATION IN TRANSIT SYSTEM BASED ON CBD ACCESSIBILITY: THE CASE OF ANKARA

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Master of Science, City Planning in City and Regional Planning
Supervisor: Prof. Dr. Emine Yetişkul Şenbil

June 2020, 226 pages

Individual automobile use appears as an attractive urban transport mode because it provides door-to-door travel regardless of how the origin-destination patterns or time variability of travel demand are complicated. Furthermore, policies and projects for accomodating the increasing car traffic in cities has given rise to creation of automobile oriented urban areas, which resulted in problems of traffic congestion, energy dependency, air pollution, social inequalities in accessibility, and finally decreasing benefits of automobile use. This brings the world into a position where the management of urban transportation demand through strategic supply of facilities is the main concern. In this respect, encouraging the use of public transportation modes is widely regarded as a sustainable alternative against automobile use. Significant investments in public transit in the recent years in terms of both capacity and technology are indicators of this reality. However, development of different public transit systems has failed to achieve providing an attractive alternative means of mobility that change the driving habit. Therefore, there has been an increasing need for integration of different modes competing in an urban transit sytem. Distinguishing between the dimensions of integration and the effects of some particular factors under these dimensions on the capacity of overcoming the space is

needed to be scientificly searched in order to both discover how efficiently the existing integration facilities operate within a given geography and to guide transit providers on the specific policy areas for improving the overall performance –that is the capacity of overcoming the space.

Departing from this point, the thesis aims to contribute local authorities and other urban transit providers to develop policies for multi-modal integration in transit system by addressing the limits of accessibility regions that an integrated system creates under a constant travel time budget. In particular it is intended to assess the impact of existing integration conditions of Kızılay-Çayyolu metro line and local bus services on its total capacity of offering access from the CBD –Kızılay- to urban parts in three assumptions of constant travel time budget as well as outlining the composition of total travel time costs –which stands for impedance- in space-time paths of the journeys, and to develop suggestions on how to improve the integration of urban rail and bus sytem particularly for time-geographic conditions of Çayyolu region in Ankara.

In this general framework, the overall problem is formulated into a question: "How the system facilities of integrated multimodal transit system affects the accessible geography?" The concept of "accessible geography" refers to the spatial and statistical measures of the overall area that could be accessible from the central business district (CBD) by travelling on the means of integrated system of metro line and its feeder bus lines. The question includes the changes in the accessible geography in relation to the existing conditions of the schedule and route integration between the two modes.

Keywords: Public Transit, Multi-Modal Transportation, Inter-modal Integration, Travel Time Cost, Accessibility, Transportation Geography

ÖZ

TOPLU ULAŞIM SİSTEMLERİNDE MİA ERİŞİLEBİLİRLİĞİNE DAYALI ÇOK MODLU ENTEGRASYON: ANKARA ÖRNEĞİ

Ayar Turan, Şeymanur
Yüksek Lisans, Şehir Planlama, Şehir ve Bölge Planlama
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Haziran 2020, 226 sayfa

Ulaşım talebinin zaman ve orijin-destinasyon değişkenlerinin ne kadar karmaşık olduğu farketmeksizin kapıdan kapıya seyahat etme olanağı sunması nedeniyle bireysel otomobil kullanımı cazip bir kentsel ulaşım modu olarak kendini göstermektedir. Bununla birlikte, kentlerde artan taşıt trafiğini barındırmaya yönelik politika ve projeler geliştirilmesi otomobil odaklı kentsel alanların oluşmasına sebebiyet vermiştir ki bu durum da trafik sıkışıklığı, enerji bağımlılığı, hava kirliliği, erişilebilirlik açısından sosyal eşitsizlik, ve son olarak otomobil kullanımından elde edilen faydanın azalması gibi problemlere neden olmuştur. Bu, dünyayı kentsel ulaşım talebinin stratejik arz politikasıyla yönetiminin temel kaygı olduğu bir pozisyona getirmiştir. Bu bağlamda, toplu taşım türlerinin kullanılmasının teşvik edilmesi otomobil kullanımına karşı sürdürülebilir bir alternatif olarak genel kabul görmektedir. Son yıllarda toplu taşımda hem kapasite hem de teknoloji bakımından yapılan büyük yatırımlar bu gerçeğin bir göstergesidir. Fakat farklı türde toplu taşım sistemlerinin geliştirilmesi araç kullanma yönelimini değiştirecek alternatif bir mobilite biçimi sunmayı başaramamıştır. Bu nedenle kentsel toplu ulaşım sisteminde birbiriyle rekabet eden farklı türlerin birbirleriyle entegrasyonuna olan ihtiyaç artmıştır. Toplu taşımda farklı türlerin entegrasyonunda etken olan faktörlerin, ulaşımın nihaî amacı olan birçok kısıta bağlı mekanın üstesinden gelme -yani başka

bir deyişle hizmet sunulan coğrafyaya erişilebilirlik sağlama- kapasitesi üzerine etkilerinin hem belirli bir coğrafyadaki mevcut entegrasyon koşullarının ne derece verimli bir erişilebilirlik sağladığını tespit etmek hem de toplu taşım sunucularına erişilebilirlik sağlama performanslarını geliştirmelerine rehber olacak bir takım strateji önerileri sunabilmek için araştırılmasında yarar görülmektedir.

Bu noktadan hareketle; çalışmanın amacı çok modlu entegre bir toplu ulaşım sisteminin belirli kısıtlar altında oluşturduğu erişilebilirlik bölgelerinin sınırlarını ve bu sınırların entegrasyonun performans kriterlerine bağlı olarak nasıl değiştiğini ortaya koyarak yerel otoritelere ve diğer toplu taşım hizmeti sunucularının modlar arası entegrasyonu geliştirmelerine katkıda bulunmaktır. Bilhassa, Kızılay-Çayyolu metro hattı ve EGO otobüs hatlarının mevcut entegrasyon performans kriterlerinin kentsel bölgelere erişim sağlama kapasitesi üzerindeki etkisini değerlendirilmei, yolculuk süresi maaliyetinin yolculuğa ait zaman-mekan diagramı üzerindeki kompozisyonunun tespit edilmesi ve kentsel raylı sistem ve otobüs sistemlerinin entegrasyonuna dair öneriler geliştirilmesi amaçlanmaktadır.

Bu genel çerçevede, araştırmanın ele aldığı temel soru şöyledir: "Çok modlu entegre toplu taşım sistemlerine ait sistem özellikleri erişilebilir coğrafyayı nasıl etkiler?". Burada bahsedilen "erişilebilir coğrafya" kavramı, metro hattı ve ona bağlantılı otobüs hatlarından oluşan entegre toplu taşıma sistemi aracılığıyla merkezi iş alanından (MİA) sabit yolculuk süresi varsayımları altında erişilebilen alanların mekansal ve istatistiki ölçütlerini ifade etmektedir. Temel araştırma sorusu toplu taşım modlarının zaman çizelgesi ve rota entegrasyonuyla ilişkili olarak ortaya çıkan erişilebilir coğrafyadaki değişimlerin ortaya koyulmasını kapsamaktadır.

Anahtar Kelimeler: Toplu Taşıma, Çok Modlu Ulaşım, Modlar Arası Entegrasyon, Yolculuk Süresi Maliyeti, Erişilebilirlik, Ulaşım Coğrafyası

Happy father’s day my dear father…

ACKNOWLEDGMENTS

The author wishes to express her deepest gratitude to her supervisor Prof. Dr. Emine Yetişkul Şenbil and Metin Şenbil for their guidance, advice, criticism, encouragements and insight throughout the research.

The author also owe a debt of gratitude to Fuat Vural from the Transportation Department in EGO for his helps to obtain the data needed and analyse them.

The author is particularly grateful to her colleagues Esra Alan and Saliha Üçpınar for their supports and constructive criticisms throughout the research and for the discussions.

The author is also deeply grateful to her family and dear husband for their patience, understanding and encouragement during the course of this work. Their support and trust kept this research going.

Finally, the author owes herself greetings and thanks for her perseverance, patience, and sacrifice throughout the four-years of workings for the degree of Master of Science.

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INTRODUCTION

1.1 Problem Definition

In the recent decades, urban dynamics have become much more complicated than ever, which has led highly inter-dependent human behaviours within urban context. One of the most important result of this reality can be regarded as significant increase in the need for mobility and emergence of highly complex factors affecting people's travel choices. However, opportunities to transport people from one space to another in accordance with all the possible travel choices are limited by diverse factors, which are mostly economic, social, political and environmental factors. Consequently, individual automobile use appears as an attractive urban transport mode because it provides door-to-door travel regardless of how the origin-destination patterns or time variability of travel demand are complicated. Furthermore, many cities in different parts of the world have been restructured through policies and projects for accomodating the increasing car traffic in cities. These policies and projects has given rise to creation of automobile oriented urban areas, which resulted in problems of traffic congestion, energy dependency, air pollution, social inequalities in accessibility, and finally decreasing benefits of automobile use. This brings the world into a position where the management of urban transportation demand through strategic supply of facilities is the main concern. In this respect, encouraging the use of public transpotation modes is widely regarded as a sustainable alternative against automobile use. Significant investments in public transit in the recent years in terms of both capacity and technology are indicators of this reality. However, development of different public transit systems has given rise to increasing need for integration of different modes competing in an urban transit system.

Integrated multi-modal urban transportation system refers to operation of different transportation modes in accordance with each others to increase the overall efficiency and service quality by providing seamless travel between a particular O-D pairs, instead of operating as competitors. It is widely regarded as a condition of increasing service quality and attractiveness of a multimodal urban transit system from the user perspective and improving the overall efficiency from the operational perspective. However, it is difficult to identify a simple set of principles to achieve a well-integrated transit system. It is mostly because there are several dimensions of integration, which are generally categorized as locational integration, timetabling integration, ticketing integration, information integration, service design integration, travel generation integration (Potter, 2010); and strategic integration, operational integration, and tactical integration (as cited in Lee, 2013). It is also known that the factors of each of these dimensions affect the overall performance of a multimodal integrated transit system in different ways. The overall performance of an integrated transit system is assessed either in terms of the total ridership or the amount of space it overcomes within the given constraints as explained by the transportation geography approach. It is because the ultimate function of transportation is to overcome space so that urban activity locations become "accessible" by users. Investing on integrated public transit systems so that they provide seamless travel options in which the constraints are minimized is also an effort for approaching the capacity of overcoming the space the public transportation systems have to those offered by automobile use.

Distinguishing between the dimensions of integration and the effects of some particular factors under these dimensions on the capacity of overcoming the space is needed to be scientificly searched in order to both discover how efficiently the existing integration facilities operate within a given geography and to guide transit providers on the specific policy areas for improving the overall performance –that is the capacity of overcoming the space.

Departing from this point, the thesis aims to contribute local authorities and other urban transit providers to develop policies for multi-modal integration in transit

system by addressing the limits of accessibility regions that an integrated system creates under a constant travel time budget. In particular it is intended to assess the impact of existing integration conditions of Kızılay-Çayyolu metro line and local bus services on its total capacity of offering access from the CBD –Kızılay- to urban parts in three assumptions of constant travel time costs –which stands for impedance- in time-space paths of the journeys, and to develop suggestions on how to improve the integration of urban rail and bus sytems particularly for time-geographic conditions of Çayyolu region in Ankara.

The discussion of integrated multi-modal public transit systems comprises of a rich array of issues. For example, there are several dimensions of integration, diverse types of transit modes, diverse economic and geographic conditions, various system parameters, etc. The scope of this thesis however is narrowed down in terms of transit modes to be integrated, which are urban rail and bus transit systems. Secondly, the discussion is limited by the investigation of timetabling integration and spatial integration of the routes among many others specifically on the accessibility regions that an integrated system provides under the given constraints.

Apparently, the thesis is mainly directed to a practical scientific problem although it seeks for grounding it on a theoretical base. Furthermore, exploratory approach is adopted throughout the study as it searches for a better understanding of the problem and possible relation between the phenomena. There is also a descriptive aspect particularly when identifying and clarifying the characteristics of the best examples in the world, and describing the concepts, issues, etc.

It is expected to contribute on relating and comparing the theoretical literature and practical examples in cities from different parts of the world. Additionally, it provides a test of criteria defined in widely accepted literature on Ankara case, specifically Kızılay-Çayyolu metro line and its links with the bus transit system. Furthermore, it is supposed to be a guide on how to improve the integration of urban rail and bus transit networks in a real life practice. Finally, this research is expected

to present a methodological example for other particular cases, although it is case-specific.

1.2 Research Questions

Having explained in the previous parts, the thesis aims to contribute local authorities and other urban transit providers to develop policies for multi-modal integration in transit system by addressing the limits of accessibility regions that an integrated system creates under a constant travel time budget. In particular it is intended to assess the impact of existing integration conditions of Kızılay-Çayyolu metro line and local bus services on its total capacity of offering access from the CBD –Kızılay- to urban parts in three assumptions of constant travel, and to develop suggestions on how to improve the integration of urban rail and bus sytems particularly for time-geographic conditions of Çayyolu region in Ankara.

In this general framework, the overall problem is formulated into a question: "How the system facilities of integrated multimodal transit system affects the accessible geography?" The concept of "accessible geography" refers to the spatial and statistical measures of the overall area that could be accessible from the CBD – central business district- by travelling on the means of integrated system of metro line and its feeder bus lines. The question includes the changes in the accessible geography in relation to the existing conditions of the schedule and route integration between the two modes.

There are also sub-questions that guide the whole research for answering the main question. The first one is "What is the coverage of geography over which the integration facilities are provided?" It is primarily needed to put forward the spatial coverage of all the elements of the integrated system so that the limits of accessible area could be identified. The stations on the metro line and the line itself are the primary elements which are not flexible in space. The bus lines that are linked to each stations and all the stops on these lines are the secondary elements which are

relatively flexible. So the overall area covering all these elements is the geography to be analyzed.

The second sub-question is “How the accessible geography is shaped in the given travel time budgets?” which helps answering the main question by seeking for how much area of the overall geography is accessible from the city center under the given time constraints. It reveals not only the areal amount but also the spatial pattern of the accessible geography. It is crucial for assessing how much space in which directions is overcome by means of the integrated system with the existing schedule and route integration facilities.

Thirdly, the question of “How the accessible geography changes in peak and off-peak periods in weekdays and Sundays?” specifically explores the effect of schedule integration on the capacity of the system to overcome the space. The timetables of both the trains and busses varies in peak and off-peak hour in weekdays and weekends. Therefore, the areas which are accessible by means of the integrated system in a given amount of time in different days and times reveals the effect of schedule integration on the overall system capacity.

The fourth one is “How the travel time is allocated on parts of a journey through the integrated system?” This question is not directly related with the accessibility that the integrated system under research provides. It could be regarded as a preliminary search for investigating how the each segment of a travel on integrated system contribute to reach the limits of accessible area, which is included in the next question.

The fifth and the last sub-question is “How the accessible geography is constrained in relation to travel time allocation?”, which goes further than representing the pattern of accessible geography and looks for the roles of each part of an overall journey on the accessibility it provides. So, the certain bus routes originated from each stations and schedule integration between the trains and the busses are assessed based on the time cost of each segment of the journeys.

After answering the questions listed above through a mix of qualitative and quantitative methods of data collection and data analysis, there will be findings on the effects of multimodal transit integration on the accessible geography within a given travel time budget, which is the main question of the thesis. However, it is not only limited by investigation of these questions but also seeks for constructing a general framework of the theories and concepts that are crucial for having an understanding of integrated multi-modal transit systems and their roles in meeting the current demand for transportation. In this context, both a comprehensive literature review and exploration of the basic characteristics of urban rail-bus integration systems in other cities in the world are included in the thesis. There will also be a reviewing of the similar studies on changes in the overall performance of urban rail systems based on the integration facilities, which is supposed to provide much more than answering the research questions. Comprehending all these phenomena based on the research, suggestions for improving the integration of urban rail and bus systems will be developed based on the implications of the Kızılay-Çayyolu metro line in Ankara.

1.3 Structure

Having declared the problem area, the research questions and the aim of the thesis, it is also needed to outline what is included before going into details.

The thesis primarily provides a comprehensive literature review constructing a general framework of the theories and concepts that are crucial for having an understanding of integrated multi-modal transit systems and their roles in meeting the current demand for transportation. It will provide further theoretical explanations about the emergence of the need for “integrated transport” and how its area of use has evolved; various definitions and descriptions of the term “integrated transport/multimodal transport/intermodal transport”; dimensions of integration; the role of integration qualityfor improving the public transit performance, depending on the findings of related studies analysed in the literature. In addition to theories of

integrated tranport, the notion of “accessibility” and its link with service quality provided by a multi-modal integrated system are to be covered as the theoretical background. It is because they provide a basis for methods of evaluating the existing sytsem performance of an integrated transit system. After having collected sufficient data of theories and descriptions, the main theories, and methods and findings of essential researches will be summarized and comparatively analyzed in order to have a comprehensive understanding of theoretical framework and limits of the issue to be studied.

Following the literature review, there will be an overview of the cases in different cities, which has considerable experiments on attempting to improve the integration of urban rail and bus systems. The Canton of Zürich and Melbourne Metropolitan Area are the cases that will be elaborated throughout the research. The method of overviewing the cases is best described under three phases: First; comprehending the socio-economic and spatial conditions of research unit. Second; associating the case to the research question through compiling its related experiences. Finally; obtaining concrete values on real life experiences in the case cities. Specifically the characteristics of bus services for transporting citizens from other parts of the settlement area to the bus stops for transferring to train stations are explored on hypothetic trips for each bus lines connected to train as sample. The determined criteria in this context are minimum, maximum, and average access time and distance to the station, and service frequency of both busses and trains –intervals-.

The qualitative data about dimensions and criteria for the concept of multi-modal transport integration as the expected output of these two sections are supposed to provide a significant background knowledge of theory and good practice for issue that the thesis centered. This knowledge will eventually be utilized to identify criteria to be tested for Ankara case. In other words, the methodology is built on the analysis of the literature review and the investigation of successful practice cases presented so far.

Having qualified with the information of concepts and their practices on world cities, the next section consists of the case specific analysis of effects of system facilities of integrated multimodal transit system on accessible geography. The first part of the section deals with determination of accessible geography under the given constraints. In this part, the geography that is accessible from the city center through the overall network consisting the metro line and its feeder bus lines in 30-45-60 minutes travel time constraints are exhibited. In this context, the first and second sub-questions described in the previous part are to be answered. It is also explored how the accessible geography is varied in peak and off-peak hours in weekdays and off-peak hours in Sunday in terms of both the spatial pattern and statistical measures, as put forward by the third sub-question. The second part of the section on the other hand explores the travel time allocation within the parts of travels which forms the accessible geography. Thus, the aspects in which the integrated system of metro line and feeder busses is weak in coping with geography is to be identified. How time cost affects mobility in space and accessible geography along certain routes under a fixed time budget will also be revealed by the time-space paths. So the fourth and the fifth sub-questions are supposed to be answered in this part.

Finally there is a concluding section in which the concepts and theories forming the basis of problem area and motivation of the research are summarized as well as the lessons learned from the world examples. The findings of the analysis on Kızılay-Çayyolu metro line and its integration with bus transit system are recovered which also starts a discussion. Finally, recommendations for the further studies are provided in the concluding section.

CHAPTER 2

LITERATURE REVIEW

This part of the paper will provide further theoretical explanations about the emergence of the need for "integrated transport" and how its area of use has evolved; various definitions and descriptions of the term "integrated transport/multimodal transport/intermodal transport"; dimensions of integration; the role of integration quality for attracting potential users for public transit, depending on the findings of related studies analysed in the literature.

Notion of accessibility and its link with the service quality provided by a multi-modal transportation system. Finally its role in determining the transport geography within any scale of settlement area. These broader therotical background is needed to be covered because they provide a basis for methods of evaluating the current conditions of Kızılay-Çayyolu metro line and feeder busses connected to it in Ankara, as an example of integrated multi-modal public transportation system.

In addition, a brief discussion of the need for this particular research and its expected contribution to the literature will be covered. Finally, the research framework will be described based on the wide array of issues presented within the literature.

2.1 Integrated Transport

The theories and concepts explained in the literature related to integrated transportation are grouped such that the emergence of the need for integrated transport, its definitions, and dimensions as well as the studies on impacts of integration on the ridership are given as individual parts.

2.1.1 Emergence of the Need for Integrated Transport

The concept of "intermodality" is first used for freight transportation. As Grava (2003) explaines, the emergence of the concept dates back to the early 20th century. Before it was on the agenda, waterways were used as the major channel for freight transportation in 18th century. As the waterways were extended inland by constructing canals, different types of waterways were formed but they were all parts of a single mode. Consequently, there were no competition among different modes of freight transportation. However, railroad appeared as a new mode of transportation in paralel to evolving economic and industrial circumstances in 19th century. The earliest railroads have connected existing cities and towns and carried passangers and freight in both directions. These railroads were often built in parallel direction to the existing water canals because it was found that railway transportation has many advantegous over waterway transportation. It offers faster, cheaper, and more reliable service than the canals in most cases, which resulted in emergence of modal competition for freight transportation. Increasing competition between the transportation modes has created a segmented and non-integrated transport system. It is mostly because each of the available transportation mode has regarded the others as competitors and tried to maximize the length of the line under their control. However, they cannot cope with certain characteristics of each mode putting them advantegous or disadvantegous positions in some particular cases. In early 20 th century, realization of disadvantegous of such a segmented system has led to a shift from segmented to an integrated transport system with an initial aim to improve the overall efficiency of shipping and gaining higher revenue all together. The key for this transition is that the entire trip from the origin to the final destination was started to be considered as a whole.

The first use of the intermodality for urban transportation is very similar to its use for freight transportation. As Grava (2003) asserts, the first items of public transportation were intercity rail stations around the center; and omnibusses and street cars inside the centers of many cities. As urban population has increase and

cities become larger and more complex, mobility need and transportation demand has increased, subsequently the orgins and destinations has become various. As a result, more options and more routes to travel for desired destinations and integration of different options is needed so as to operate more efficiently as a whole. The most obvious result was the chains of stations surrounding the cores of London, Paris, and some other metropolitans especially in Europe.

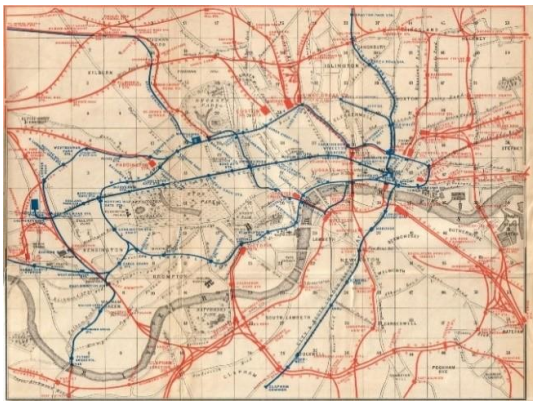


Figure 2.1 London Rail Map, 1889

Source: (https://www.transitmap.net/ london-1889/)

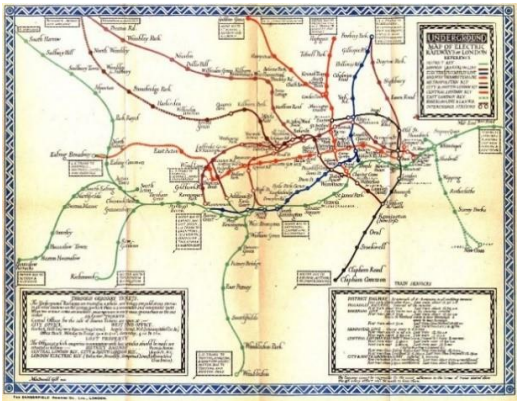


Figure 2.2 London Rail Map, 2000

Source: (Source:https://londonist.com/2016/05/the-history-of-the-tube-map)

Figure 2.4 Tokyo Rail Map, 1914

Source: (http://www.oldtokyo.com/tokyo-station-1914-1940/)

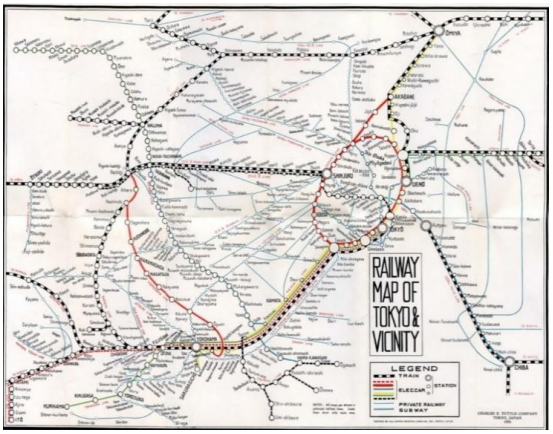


Figure 2.3 Tokyo Rail Map, 1959

Source: https://www.flickr.com/photos/tigerzombie/6538959095

It is well presented in the London rail map of the 1889 in Figure 2.1 how the intercity rails are concentrated around the center and how they are integrated to each others by the links of intracity rails that are constructed later. As it is obvious in Figure 2.2 the modes of intracity rail transportation have become various in the 20th century although the rail was still the dominant mean. Furthermore, there are much more diverse routes in the city center which have several Figure 2.3 and Figure 2.4 show the rail stations around the city center of Tokyo, that are constructed in late 19th century and early 20th century, and then how they are connected through several routes and stations of eleccar system in the late 20th century. Apparently, integration of different routes and means of transportation has usually standed for their physical integration.

Although there were some early examples of modal integration, special emphasis is put on the term "intermodality" in the late 20th and early 21st centuries (Grava, 2003). It was mainly because of increased use of private cars and environmental concerns. It is obvious from EU's identification of "intermodality" as a requirement because it offers more efficient, more safer, and more comfortable transportation system that can eliminate incresing use of private cars. It is inferred that since its first use in freight transportation, multimodal integration in transportation systems have been used for various purposes depending on the contemporary economic, environmental, social concerns. Consequently, there are several descriptions that refer to integration of various transportaion modes, and definitions that have slight differences because of their particular emphasises despite the common assertions they have.

2.1.2 Defining The Integrated Multimodal Transportation

Integration is defined by the final report by NEA (Transport, Research and Training), OGM (Organisation Gestion Marketing), and TSU (Transport Studies Unit) in University of Oxford on integration and regulatory structures in public transport (2003, p.7) as "an organizational process that enable an efficient interaction among the elements of passenger transportation system across modes, operators, sectors and institutions with the aim of increasing net social benefit from the enhancement in

overall quality of the service." This definition clearly indicates that integration in public transportation in the 21st century covers not only the level of physical interaction among routes and modes at the end, but also the whole process of achieving a coordination between various stakeholders that either plan or operate the transportation facilities. Another identification for transport integration at the practical level implies that "whatever modes or types of transport are involved they all operate as one seamless entity for the benefit of the customers" (Givoni & Banister, 2010, p.242). In contrast to the previous definition, this one focuses on to what extend the network of transportation is capable of providing trips without any interruptions regardless of what modes or stakeholders are involved or what actions are taken.

Givoni and Banister (2010, p.5) mentions that integration within the transport network often relates to the terms "multimodal" and "intermodal", which are used interchangeably, but in general reflect the use of more than one mode of transport within one journey (of passengers or good) and/or the consideration of more than one mode of transport (e.g. in transport policy).

In the US, integration of transportation modes is known as "intermodalism". It is defined as "the coordinated passage of goods and people by way of two or more of the primary modes of transport from origin to destination as defined by the passenger or the shipper and consignee, with a single travel directive bill of lading or ticket and a single price covering the entire trip" (Alt et al. 1997, p34). Intermodalism has also been defined as: "a system that is both safe and efficient and productive and flexible in responding to the needs for good movements and offering choices and flexibility for people in their personal movements" (Jeff, 1998, p.13). These two definitions from the late 20th century still put emphasis on intermodalism in freight transportation as well as passenger transportation. Moreover, it is inferred from these definitions that considerations such as integration in pricing have gained importance in addition to physical integration of transportation modes when shifting into the 21st century. Similarly, considerations such as safety, flexibility, and wide range of travel options -which are for benefit of the users- have come into the agenda in addition to

efficiency concerns in 19th and 20th centuries. Another definition for intermodalism is proposed by Szyliowicz (2010, p.32) as “a system in which the individual modes are linked, governed, and managed in a manner that creates a seamless and sustainable transportation system”. Szylowichz also indicates that such a system should be economically efficient, environmentally sound, safe & secure, and ethically based.

Intermodality is also mentioned in the European Commission’s White Paper on Transport Policy of 2001 (COM, 2001) and subsequently in the Mid-Term Review of the Transport White Paper of 2001 (COM, 2006) the Action Plan for the Deployment of Intelligent Transport Systems in 2008 (COM, 2008), and finally the EU Transport Policy in 2011 (COM, 2011). In relation to the terms intermodality and multimodality, the EU has adopted the term “co-modality”, and defined it as “the efficient use of different modes on their own and in combination, resulting in an optimal and sustainable utilization of resources” (COM, 2006, p.31.)

Table 2.1 Summary Terms & Definitions Referring Integrated Transport

Author (Date)	Term	Subject	Main Concerns	Components	Aim
NEA, OGM, and TSU (2003)	Integration (in transport)	Organisational process	Bringing together the planning and delivery of transportation facilities	Modes Sectors Operators Institutions	Increasing net social benefit
City Transport Info (2001)	Transport Integration	A system	Operating as a seamless entity	Modes or types of transportation	Benefit of the customers
Givoni & Banister (2010)	Multimodal / Intermodal	Use of	(n.m)	More than one mode of transport	(n.m)
Alt et al. (1997)	Intermodalism (in the U.S)	(n.m)	Coordinated passage of goods and people	Two or more of transportation modes Single travel ticket Single price	(n.m)
Jeff (1998)	Intermodalism	A system	Safety Efficiency Productivity Flexibility	(n.m)	Responding to the needs for good movement Offering choices and flexibility for personal movement
Szyliowicz in Givoni & Banister (2010)	Intermodalism	A system	Linking, governing and managing individual modes	(n.m)	Seamless, sustainable, economically efficient, environmentally sound, safe & secure, and ethically based transportation
COM (2006)	Co-modality	Use of	Efficiency	Modes	Optimal and sustainable utilisation of resources
Vuchic (2007, p.439)	Transit System Integration	A system	Direct travel opportunity	Single payment, various modes and lines	To annihilate the disadvantages of the transit against the private car use

Summary of the definitions proposed for the terms that are associated with integrated multimodal transportation in the literature is given in the Table 2.1. It shows that multimodality, intermodality, co-modality, and transport integration are the terms used for referring to integration of more than one mode of transportation. It is usually described as a system the components of which are well-connected, but there are also other approaches focusing more on the whole process of acting in coordination. Considering the components of transport integration, it is evident that the core element is the different modes of transportation such as bus, tram, metro, private car, etc. There are also some clues that the concept of transport integration actually covers a wider array of issues such as price integration, institutional integration, operational integration, sectoral integration etc., which will be elaborated in the following pharagraphs. Another conclusion is that the prominent area of use for the concept of integrated transport is urban transportation and public transit in the recent years while there are still an emhpasise on integration in freight transportation in the early definitions. Additionally, the early definitions generally explaines the aim and main concerns of integration through economic efficiency and productivity. However, there is an increasing reliance in the later definitions on enhancement of benefit of the users. Attributes such as seamlessness, security, and flexibility are considered to be standing for user satisfaction rather than economic efficiency, which indicates that approaching to the urban transportation from the user perspective has gained importance in time. This can well be explained by shifts in the motive behind exalting transport integration from minimizing time and money cost of transporting goods to create attractive alternatives for urban passenger transportation against increasing dependence on private cars and accompanying problems.

2.1.3 Dimensions of Transport Integration

It is difficult to identify a simple set of principles to achieve a well-integrated transit system. It is mostly because there are several dimensions and parameters of integration, which are generally categorized as locational integration, timetabling

integration, ticketing integration, information integration, service design integration, travel generation integration (Potter, 2010). According to categorisation of Potter (2010) after an exploration of overlapping layers of meanings of integrated transport, locational integration –as the core dimension- refers transportation services to be connected in space and make it possible to easily change between transport modes mostly by using interchanges. Timetabling integration in the second sequence corresponds to services operating based on a coordinated time schedule, and ticketing integration stands for a pricing system in which one single ticket is valid for the whole journey. Information integration as Potter (2010) explaines covers all the methods and technologies providing required information for users to easily get desired services. Next, service design integration refers to the legal, administrative, and governance structures encouraging operational integration. Finally, there is another dimension corresponding to integration of transport planning with travel generators –land uses- which is described as travel generation integration.

Another framework developed by Van Oort (2011) divides measures of a reliable interchange among modes into three categories, which are strategic, tactical, and operational integration. The strategic category includes the measures that can be taken through network design such as line length and line coordination, stop spacing, terminal designs etc. The tactical category corresponds dealing specifically with timetable design, similar to the "timetabling integration" proposed by Potter (2010). The measures studied by Van Oort (2011) under this category are trip time and vehicle holding, dealing with the allocation of disaccordance in the timetable. Operational improvement category covers all the actions of managing, operating, and maintaining the transportation services.

Chowdhury and Ceder (2013) developed a typology for defining the five integration attributes. Accordingly, an integrated public transport system has five main attributes, which are network integration, fare integraion, information integration, physical integration, and coordinated schedule. It is proposed that a suitable integration of elements of a network diminishes wasteful duplication of routes and services and thus provides a better utilisation of resources. It is an essential element

of a integrated transport because routes are required to be connected with one another to create access for a wide range of destinations by public transportation. A common global approach in the development of integrated multimodal transport systems has been fare and ticketing system information. Fare system integration has been considered to facilitate seamless transfers and consequently encouraging the use of routes with transfers. Furthermore, an information system that assist transit users and provide guidance on route, thereby reducing the chances of missed connection is considered as an important requirement for a system to be totally integrated. Integrated physical connection for transfers refers to terminals that physically connects the routes and stations of different modes and ease the transfer. Finally, the aim of integrated timed-transfers is to interconnec the multimodal public transportation network such that the transfer time is minimized.

Luk and Olsewski (2003) argue that intermodal integration involves five general categories: Physical, transport network, fare, information, and institutional/administrative integration. It is claimed that the physical proximity and ease of access at mode interchanges greatly anhance the use of public transport services, therefore passengers should be within a short walking distance from the transit stops. It is supported by Luk and Olsewski (2003) that various lines of different modes should form an integrated network by complementing one another. It is widely suggested that feeder services using buses, trams, or light rail should be designed to maximise the patronage. In addtion to these, transfer between modes should be facilitated through availability of a single fare card for multiple transit services and a well-designed signage at transit stations. Finally, cooperation and coordination among government agencies and other operators is essential to management of an integrated transit system. Integration model of the community of Madrid (Cristobal, 2011) includes administrative, fare, and modal (physical and operational) integration, that can be considered as relatively more rough categorisation. Nevertheless, administrative and ticketing aspects of an integrated transport system are underlined in parallel to the previous descriptions.

There are not only multiple dimensions of an integrated system but also various parameters under these dimensions that are used for assessing the level and quality of integration. A study on integration of Beijing's metro and bus networks reveals that travel time and transfer time are the two indicators of service standard aspect; peak period load factor, degree of overlap, and coverage of bus stations as indicators of network structure aspect; and bus revenue as the primary indicator of operational aspect of an integrated transport system (Song, L., Chen, F., Xian, K., & Sun, M., 2012). Chuwdury and Ceder (2013) proposed a much more wider array of parameters that have an affect on quality of integration attributes. Although their categorisation does not provide an exhaustive list, it provides a good direction for related studies. The list covers physical overlap of service lines, availability of feeder services, network coverage, and accessibility of public transit network constituting the "network integration"; transfer wating time and level of syncronisation for describing schedule integration; availability of shelter, security, directional signage and maps forming physical connection; en-route guidance, online maps and timetables, journey planner applications for the dimension of information integration; and finally smart cards and no additional cost for transfers comprising the fare and ticketing integration.

There are also several studies testing the most prominent attributes for understanding the level and quality of integration in transportation system, mostly from the user perspective. Factors such as personal safety at interchange terminals, reliability of connection, transfer time and availability of information related transfers are established as the most important operational indicators of user satisfaction with the integration quality in a system (Chowdhury, and Ceder, 2016). Network integration through transfers includes functional design of lines, the optimal layout of transfer stations, coordinated scheduling, information, and joint tariff (Vuchic, 2005). The results of the modelling by Schakenbos, La Paix, Nijenstein, & Geurs (2016) on the other hand revealed that total disutility of transferring from one mode to another depends essentially on travel time, distribution of the time spent either on access, transfer, or waiting time, and headway. In parallel to these, Currie and Willis (1998)

have found that passengers in Melbourne displayed a consistent preference for improvment of timetable and information provision, followed by the concerns about service frequency. However, they also revealed that public transit users place a high value on basic amenities for comfort at interchanges, such as availability of seating and shelter. This is supported by the explanation of Hale and Miller (2013) that station environment plays an important role in user's experiences and therefore their perception of quality of integration, especially considering the multimodal stations. Finally Vuchic (2005) argues that passengers must be considered as the most important party since they are customers for whom the system is provided. If their requirements are not met and transit service does not attract passengers, both the operator and the community suffer loses. The most prominent passenger requirements are availability of service, frequency/headway, speed, comfort, convenience, security/safety, punctuality, and user cost as summarized in Table 2.2.

Table 2.2 Dimensions and Parameters of Transport Integration

Author (Date)	**Dimensions of Integration**	**Parameters**
Potter (2010)	Locational Integration	• Diversity of travel options • Availability of interchanges
	Timetabling Integration	• Accordance in schedules
	Ticketing Integration	• Availability of multi-modal ticketing
	Information Integration	• Availability of real-time information • Signposting and guidance around interchanges
	Travel Generation Integration	• Integration of transportation planning and land-use planning

Van Oort (2011)	Strategic Integration	• Measures related to network design such as:
		  ○ Line length
		  ○ Line coordination
		  ○ Stop spacing
		  ○ Terminal design

	Tactical Integration	• Measures dealing with timetable design as
		  ○ Travel time
		  ○ Vehicle holding time

	Operational Integration	• All the actions of
		  ○ Managing
		  ○ Operating
		  ○ Maintaining

Chowdury and Ceder (2013)	Network Integration	• Physical overlap of lines • Availability of feeder services

		• Network coverage • Accessibility of PT network
	Fare Integration	• Smart cards used for all services • No additional cost for services
	Information Integration	• Real time information at stations • En-route guidance • Maps and timetables for all PT services
	Physical Integration	• Sheltered walkways to the stations • Security measures • Directional signage to link stations
	Schedule Integration	• Transfer waiting time • Level of synchronization
Luk and Olsewski (2003)	Physical Integration	• Physical proximity • Ease of access to stations
	Network Integration	• Complementary lines • Feeder services
	Fare Integration	• Single fare card
	Information Integration	• Signage at stations
	Institutional/Administrative Integration	• Coordination among government agencies
Cristobal (2011)	Modal (physcal & operational) Integration	
	Fare Integration	
	Administrative Integration	

Song et al. (2012)	Service Standard	• Travel time • Transfer time
	Network Structure	• Peak period load factor • Degree of overlap • Coverage of stations
	Operational Aspect	• Revenue

Although multimodal integrated transportation is highly promoted by both academic researches and policy documents especially in EU, it is possible to argue that there are some drawbacks that detain service suppliers from putting the requirements of multimodal integrated transport into practice. These drawbacks are generally originated from disutility of transfer from the user perspective, and perceived disutility of investing in the integration from the supplier perspective. As illustrated in (Holvad, 2010) a typical journey in a multimodal integrated system consists of walking to bus stop, (where the bus is the primary option for accessing rail network), waiting for bus at the stop, riding a bus, walking from bus stop to a rail station, waiting at rail station to ride, travel by train, walking from rail station to the final destination. Apparently, there are several interruptions for a journey from origin to the destination when transferring from one mode another is needed in a multimodal integrated system. Each of these interruptions causes some particular costs – disutility- fort the public transit users.

The term “transfer penalty” is used to refer to all monetary costs, time, inconvenience, and stress experienced by public transit users when making transfers during a journey (Holvad, 2010). The study done by Iseki at al (as cited in Holvad, 2010) shows that transfer penalties for a typical journey would account for 26 percent of the total cost of the journey. The main components of the transfer penalties or transfer disutility are revealed as walking time and waiting time. Several studies

supports that travel time, distribution of travel time, and additional fare are the main disunities of transfer from the user perspective.

There are also disutility that drawback the suppliers from investing on improving the integration. Considering the practical aspects, these drawbacks are generally originated from the estimated costs of an improvement in the integration and unawareness of suppliers about the possible returns of these improvements on the overall system. In a survey conducted by the US Federal Transit Administration (1996), only three out of 31 operators surveyed specified objectives for the transfer system in relation to passenger or operating convenience, revenue generation, or other factors. Many operators pay little attention to passengers' transfer behavior and do not consider transfers part of their overall service delivery philosophy. A similar survey conducted in 20 European cities by the European Commission found that many operators did not even know the volume of transfers taking place in their systems (GUIDE, 1999). Only one city, Copenhagen, has integrated timetables, where coordinated timetables are produced and all-mode timetables are issued (GUIDE, 1999). In general, there is no tradition of treating transfers as a part of the service supplied, which actually affects their revenue in the long-run. Consequently, for the supplier bodies for example a policy to invest on a better or longer rail service outweighs investing on improving the access to the rail service or integrating it with other transportation services, when accounting the likely costs and expected benefits involved. Regarding how to improve access to the railway station, the suppliers need to consider enhancing feeder services to the stations, increasing the frequency of service in order to reduce the travel time, and improving the transfer station qualities which are recognized as additional cost of operation ignoring the potential contributions on the total ridership and revenue (Brons, Givoni, & Rietveld, 2009).

2.1.4 Studies on Impacts of Integration on PT Ridership

There are several arguments in the literature that inconvenient transfers in a multimodal integrated system could deter potential customers, or a well achieved integration could attract much more customers. Vuchic (2005, p.569) critisizes a common misconception of transfers when travelling from an origin to a destination are not tolerable, and the riders do not use transit if they need to transfer on a route; and proposes that passengers easily accept transfer in the best transit systems with good station design, frequent service, and reliable operations. Matas (2004) investigated the significant (40%) increaseof PT use in Madrid,Spain and found the reason to be integration. The study discussed that integrated fare system and network integration had the most impact on ridership. Preston, Marshall, & Tochtermann (2008) concluded from design procedure generating feeder routes and frequencies that the feeder routes imply a more integrated transit network with a reduction of the total travel time, despite an increase of the number of transfers, in a more efficient way as demonstrated by the reduction of the operating costs and the increase of the average load factor. Ridership of a transit system could well increase when access from residential areas to transit station is improved in terms of physical environments and sense of security (Supaporn et al., 2013). Similarly, Selmer and Hale (2010) explained that quality of passenger access to stations and egress to destinations represents effectiveness of mass transit. It also affects ridership and income of the system. It also encourages car users to be mass transit users and inspires non-regular mass transit users to be regular mass transit users (Givoni et al., 2007 and Brons et al., 2009). Banister (2010) also confirms that it is not suprising that the private car is usually seen as the most attractive choice, as it involves the use of only one of the transport sub-networks where integration of transport sub-networks is absent on the supply side.

The term of intermodal integration covers various different modes with all types of available technology and their integration in various combinations. Within the literature review until this part, there is no special emphasize on how and under

which conditions each of modes are to be integrated one another. It is because investigating principles of integrating different modes in various combinations includes too wide array of issues to be covered in one particular research. However, the following paragraphs will be going through the researches on urban rail transit and bus transit integration in cities. It is mainly because a rail journey is rarely an end self. On the contrary, it is almost always part of a journey "chain" that includes a journey to and from the railway station by diffeent modes of transport. The integration of these components is essential to achieve a continues travel, door-to-door journey when using rail, and in order to make rail an attractive alternative to the car. Furthermore, these before and after parts of the journey could be an important part in the decision whether to use rail at all (Givoni & Rietveld, 2010).

The integration of rail transit and bus transit in multimodal networks is widely seen as a critical step toward achieving higher overall transit patronage and improved system efficiency. Each mode plays an important role in this network structure (May, 1991; Stanger & Vuchic, 1979; Thompson, 1977). Findings from researches on access to railway stations, multimodal public transport and on the inconvenience associated with the need to change vehicles during a journey all indicate that the accessibility of the railway station can be a factor in determining if rail is chosen as a travel alternative. (Hine and Scott, 2000; Wardman and Hine, 2000; Wardman and Hine, 2000). Brons et al (2009) examined how important the 'access-to-the-station' is to passengers in their overall satisfaction with the rail journey for the case of Netherlands. The conclusion reached is that in many parts of the rail network improving and expanding access services to the railway station can substitute for improving and expanding the services provided on the rail network and that it is probably more cost efficient when the aim is to increase rail use. Another study by Tabassum et al. (2017) analyzed the significance of a systematic feeder service, over conventional public modes is highlighted, based on the hypothesis that a regular feeder service will improve the accessibility of the main system that will eventually raise the ridership by shifting commuters from their private automobiles. Depending on the result that the provision of a regular feeder from the origin point could attract

more riders, it is proposed that the route and schedule of feeders that yield minimum travel delay, must be carefully worked out and maintained.

There are many other issues of rail transit system and bus service integration than quality of access facilities to the rail stations, which is not surprising when considering the several dimension of integrated transportation explained. Chowdhury and Chien (2002) examine transfers between trains and buses. Trains are given a deterministic arrival pattern, while buses are given a stochastic arrival pattern. A numerical search algorithm is used to determine which services to coordinate by finding the set of coordinated services in a trunk-and-feeder network that lead to the minimum total cost. They concluded that schedule coordination is not worth attempting for routes with a high standard deviation of arrivals. Coordination with integer headways is preferable, when some headways are relatively large. Schakenbos et al. (2016) on the other hand grounded the principle of improving the quality of integration between BTM (feeder bus-tram-metro) and train on reducing the experienced disutility of transfering. A set of mixed logit models was estimated through the research, including sub-models by trip purpose, travel frequency, access/egress mode and journey stage (access oregress). The modeling results show that the total disutility during the interchange depends on the total time, the distribution of the time spent (access, transfer, waitingtime) and headway. Finally, Brown and Thompson (2008) examines the relationship between service orientation, bus–rail service integration, and transit performance in U.S. metropolitan areas. Metropolitan areas that have integrated their rail transit into a decentralized network structure are found to enjoy higher riding habit, higher service productivity, and better cost-effectiveness than metropolitan areas with other network structures or modal combinations. These findings suggest the need for transit managers to consider the relationship between service orientation and bus–rail integration to better serve their customers and improve overall transit performance.

Table 2.3 Studies on Effects of Integrated PT on Ridership

Author (Date)	Objective of the Research	Data	Method	Case	Result
Chowdhury and Chien (2002)			Numerical search algorithm		Schedule coordination is not worth attempting for routes with a high standard deviation of arrivals.
Matas (2004)	To identify the underlying factors behind the significant increase in PT demand in Madrid	Annual data of registered trips	Estimating demand model with respect to the main PT attributes	Madrid	PT ridership can be revearsed through integration (integrated fare system and network integration had the most impact on ridership.
Vuchic (2005)					Passengers easily accept transfer in the best transit systems with good station design, frequent service, and reliable operations.
Brown and Thompson (2008)	To examine the relationship between service orientation, bus–rail service integration, and transit performance	Secondary transit data of passenger miles, vehicle miles, total operating expense from Florida Transit Information System (FTIS)		45 metropolitan areas in the US	Metropolitan areas that have integrated their rail transit into a decentralized network structure are found to enjoy higher riding habit, higher service productivity, and better cost-effectiveness than metropolitan areas with other network structures or modal combinations.

Preston, Marshall, & Tochtermann (2008)	To develop a procedure that simultaneously generates routes and frequencies of the feeder bus network that maximize service coverage area and minimize overall tt	Skeleton of road network	Heuristic algorithm k-shortest path algorithm	Winnipeg and Rome	Feeder routes imply a more integrated transit network with a reduction of total travel time, despite an increase of the number of transfers, in a more efficient way as demonstrated by the reduction of the operating costs and the increase of the average load factor.
Brons, Givoni, and Rietveld (2009)	To evaluate how important the access-to-the-station is to passengers in their overall satisfaction with rail journey	Dutch Railways customer satisfaction data	Customer Satisfaction survey Derived importance technique Reggression analysis	Netherland	Improving and expanding access services to the railway station can substitute for improving and expanding the services provided on the rail network and that it is probably more cost efficient when the aim is to increase rail use.
Semler and Hale (2010)	To review the literature exploring station-area access planning, and the emerging field of non-auto transport evaluation methods.	Literature	Literature review		High quality passenger access to rail stations represents system efficiency, an affect ridership and income of the system positively
Supaporn et al. (2013)					Ridership of a transit system could well increase when access from residential areas to transit station is improved in terms of physical environments and sense of security
Schakenbos, La Paix, Nijenstein, and Geurs (2016)	To quantify the experienced transfer disutility of a transfer between BTM (feeder bus-tram-metro) and train.	Stated preference data	Web-based stated preference (SP) experiment mixed logit models	Netherlands	Total disutility during the interchange depends on the total time,the distribution of the time spent (access, transfer, waitingtime) and headway
Tabassum, Tanaka, Nakamura, and Ryo (2017).	To assess the significance of a systematic feeder service over conventional public modes	Passenger satisfaction data	Field Survey Gravity Model	Lahore/Punjab	Provision of a regular feeder from the origin point (mainly residential) can substantially attract more riders.

To summarize, there are some particular keywords about integrated multi-modal transportation and its dimensions attained from the related literature. Initially, "seamless operation" and "direct travel" are the two prominent concerns of integrated transport as revealed in the Table 2.1. Moreover, "benefit of the users", "optimal utilisation of resources", "eliminating the disadvantages of transit against private car use" are the most common aims of transport integration explained by different researchers. That is; there is a broader motive for potential public transit users to rationally decide whether an integrated multi-modal transit system that requires transfers provide a "benefit" to them.

There are also some disutility of transfer from the user perspective as explained in the related literature review part above. Illustration of a typical journey in a multimodal integrated system well justifies the source of these disutility. It consists of walking to bus stop, (where the system includes rail line and feeder bus lines), waiting for bus at the stop, riding a bus, walking from bus stop to a rail station, waiting at rail station to ride, travel by train, walking from rail station to the final destination, or vice versa. Obviously, a single journey between particular origin and destination is interrupted several times and split into several trips. Each of these interruptions causes some particular costs –disutility- for the users. The term "transfer penalty" which refers to overall cost experienced by transit users making transfers and "walking time", "waiting time" and "distribution of travel time" as main components of transfer penalty or transfer disutility are promoted as key concepts in the related literature.

Similarly there are also some key conclusions about the impacts of integration on public transit (PT) ridership, which have motivated the aim of this research. Essentially, it is gained that ridership of a transit system could well increase as access from residential areas to stations is improved (Preston, Marshall & Tochtermann, 2008; Givani et al, 2007; Brans et. Al. 2009; Selmer and Hale, 2010; Supaporn Et. Al. 2013). Additionally, improving the qualities of integration between feeders and primary rail line depends on reducing the experienced disutility of transferring (Hire and Scott, 2000; Brons Et. Al. 2009).

It is understood that the key concepts and key findings described above that integration is a tool for users to fulfill a purpose with a certain “benefit” criterion. This benefit is to reach from one place to another despite the various constraints mentioned as "impedance". It is useful to review these concepts and the studies made about them, including the explanation of transportation with space and analysis of the spatial dimension.

2.2 Transport Geography and Accessibility

The theory of transportation geography explaines the ultimate function of transportation is to overcome space, which is constrained by various human and physical factors such as distance, time, administrative divisions and topography (Rodrigue, Comtois & Slack, 2013). According to the theory, one of the most basic measure of transportation is the amount of space that is overcome within a given time constraint. The faster the mode, the larger the distance could be overcome within the same amount of time. When a transportation system enables easier, faster and cheaper access between different places –as a result of improvements in transportation sytstem- it leads a space/time convergance because the amount of space that could be overcome within the same time constaint increases significantly (Rodrigue, Comtois & Slack, 2013). Transport geography, as the core theory for space-related transportation works, includes four common models: Distance (impedance), Accessibility, Spatial Interactions, and Transportation/Land Use Models, each is building upon the other. Distance is the most fundamental element in transportation geography, which can be represented simply by Euclidian distance or complex estimation of a logistical distance. It is also e prerequisite for accessibility model, which is simply defined as the measure of the ability of a location to be reached. In this regard, “accessibilty” is inevitably the key concept relating the field of transportation systems to city planning discipline. Such that, transportation activities are eventually for overcoming space so that urban activity locations become “accessible” by users within particular constraints. So, the quantity and

quality of service provided by a given transportation system determine how much the serviced area/geography is accessible by the users. This point of view will be constituting the approach of this study to evaluating the integration performanse of the case public transit system.

2.2.1 Measures of Accessibility

Accessibility was defined and operationalized in the past studies in various ways based on the context of the problem and its area of use. As an example, Dalvi and Martin (1976), Song (1996) consider accessibility as a measure of how easily a certain location could be reached while it is also considered as an attribute of people indicating how easily he could reach particular activity locations by Guy (1983), Hanson and Schwab (1987) (as cited in Kwan, 1998).

In addition to its variations as place and individual accessibility, the measures of accessibility also differs in terms of their complexity. As cited in Kwan (1998), by the simplest terms; there are simple measures expressing physical connection or seperation between pairs of origin/destination, as well as more comprehensive measures which determines the accessiblity through the urban surroundings and space-time autonomy of individuals (Burns 1979, Miller 1991, Villoria 1989). The former refers to integral measures of accessibility based on the concept of geographical proximity to a single reference location, while the latter indicates space-time measures evaluating accessibility in terms of an individuals ability to reach activity locations given the daily activity program an spato-temporal constraints. As the most widely utilized accessibility measures, the gravity-type (GRAV) and cumulative-opportunity (CUM) indices are integral measures of accessibility. The Gravity-Type accessibility measures (GRAV), which was introduced by Hansen (1959) are obtained by calculating the opportunities in a given area by a measure of attraction and discounting it by a measure of impedance. Based on the context of the problem, various measures of attraction and impedance have been used. However, a function of travel time or distance is commonly used as the

main variables as indicators of impedance. Cumulative Opportunity Measures (CUM), which are also named as isochronic indices, determines the degree of accessibility in terms of the number of the activities that can be reached within a given constraints of travel time or travel distance from a specific location (Black, Kuranami, and Rimmer 1982, Breheny 1978, Hanson and Schwab 1987, Oberg 1976, Sherman, Barber, and Kondo 1974).

Unlike integral accessibility measures grounded on geographical proximity to a unique referance location, Space-Time (ST) measures appraise accessibilty in terms of personnal ability to get activity locations given individual activity sequence and spatio-temporal constraints. All space-time measures were developed based on Hagerstrands' (1970) time-geographic framework. Participating in any kind of activity requires allocating limited available time to access and conduct the activity according to the time geography framework. The Space-Time Path and Space-Time Prism are two concepts central to time georgraphy. The Space-Time Path reveals the each parts of the movement of an individual in space and time with two essential components. One is control points in a sequence of time and space, and the other is the path segments that connect temporally adjacent control points. These unobserved segments are defined by interpolating two adjacent control points using time as a parameter (Miller, 2005). The space-time prism is an extension of the path and measures the ability to reach specific locations in space and time given the location and duration of particular activities. Lenntorp (1976) used the volume of the space-time prism and the area of its projection on planar space as measures of accessibility (as cited in Kwan, 1998). Accordingly, an activity is not feasible to participate in –that is accessible- unless its location intersects with the prism spatially and temporarly. Alternatively, Burns (1979) derived two accessibility measures in terms of the space-time autonomy of individuals using the prism construct. Miller (1991) developed an operation method for implementing the space-time prism using GIS procedures. Space-Time (ST) measures of accessibility could well account for complicated travel behaviors –such as multistop trips or trip chains- as they are not grounded on a single origin but regards the sequence of individual activities. But ST

measures are highly difficult to be operationalized because practical algorithms for handling the complexity of real world transportation networks is lack. Travel diary data is mostly commonly required for analyses depending on ST measures.

2.2.2 Accessibility as an Aspect of Public Transit Systems

Given the variations of place and individual accessibility and their measures, the concept of accessibility is widely considered as a critical aspect of transit sytems. It was asserted that the service provided by a given transportation system determine how much the serviced area/geography is accessible by users. Accordingly, there are many researches on utilization of accessiblity measures to evaluate either the accessiblity of transit services or the spatial accessibility that is provided to particular locations by a given transit system.

The study by Mavoa, McCreanor & O'sullivan (2012) exhibits a review of researches on accessibility in relation to transit sytstems. They classified the transit-related accessibility measures dealed in many researches into three categories. The first category named as "access to transit stops" includes the studies which evaluates public transit by focusing on physical proximity to the stops (Biba et al., 2010; Currie, 2010; Furth et al., 2007; Gutierrez and Garcia-Palomares, 2008; Hsiao et al., 1997; Kimpel et al., 2007; Lovett et al., 2002; Zhao et al., 2003 as cited in Mavoa et. Al., 2012). Accessible space via given public transit stops have been determined through Euclidean distances and network distances to the stops. Nonetheless, it is widely confirmed that buffers based on Euclidean distance overestimate the service area and thus the network distance is more preferable measure (El-Geneidy et al., 2009; Horner and Murray, 2004 as cited in Mavoa et. Al., 2012). The second category is constituted by "duration of transit journey", highlighting the travel time taken to access to a destination from a particular origin, which is most likely a transit stop. The models using travel time as a measure of accessibility achieve to include the duration aspect into evaluation of transit accessibility. O'Sullivan et al. (2000) used isochronic analysis as a method to investigate public transit accessibility by

mapping the geography accessible by travelling on a given transit system. Benenson et al. (2009) proposed use of detailed transportation network to assess the accessibility (as cited in Mavoa et. Al. 2012). It consists driving time, bus lines and stops, detailed schedule information of bus service, and real world estimates of travel speed reflecting the effect of congestion. Lei and Church (2010) intrdouced GIS based attribute of bus service time as a measure of accessiblity, which also takes the time of the day into consideration that is lack in the earlier models. The third category refers to ability to "access to final destinations", which is the essential component of overall accessibility. It makes the transit accessibility appraoch to go beyond considering the accessibility of the physical network and include the ease of getting to a particular location. This is achieved purely by spatial accessiblity measures as described in the place-based appraoch to accessiblity in the study of Huang and Wei (2002). Later models have combined travel distance and time as measures for multimodal transportation. Yiğitcanlar et al. (2008) constructed a GIS based Land Use and Public Transport Accessibility Index (LUPTAI) considering both the land use and public transit attributes such as walking distances, PT travel time, and transit service frequencies.

Depending on the similar logic behind the classification The study by Mavoa, McCreanor & O'sullivan (2012), Lei & Church (2010) have grouped accessibility measures into six categories including both the components of integral measures (GRAV and CUM) and those of space-time (ST) measures. The "system accessibility" as the first category metrics deals directly with physical access to a network based on the distance, time or any type of effort to reach access points. Nyerges (1995) simply set quarter-mile buffers around a given transit network using GIS application (as cited in Lei & Church, 2010). The area overlapping with a buffer area is assumed to have a good access to the transit system or to be highly accessible via public transit. Azar et al. (1994) – assumed that employees who lived within a quarter-mile buffer of any transit line had good accessibility to medical institutions in Boston (as cited in Lei & Church, 2010). Regarding the larger size analysis unit, Hilman and Pool (1997) have searched for a software which calculates the proximity

of users to transit stops. Furthermore, Polzin et al. (2002) added the aspect of the time of date to description of physical access by considering the variations in spatial and temporal dimensions of demand. They presume that a proportion of users are discouraged to wait for service if the headway becomes larger, and thus the accessibility falls (as cited in Lei & Church, 2010). System accessibility measures as identified above disregards the travel cost acquired to use the transit system to reach to a particular destination in addition to the cost to access to the network. Therefore, it is likely to exaggerate the accessibility level provided as a result of undersetimation of overall cost of travel.

The second category of acceesibility metrics is "system facilitated accessibility", taking into consideration the cost of travelling via a particular transit network. The context of the application and data availability determines the designation of travel cost. As the simplest way, Liu and Zhu (2004) appraised the travel time via transit by dividing travelled distance to the average speed if given (as cited in Lei & Church, 2010). Alternative models take into the time costs of transfer and wait and schedule information into consideration. Hillman and Pool (1997) designed an algorithm for determining overall travel time based on summation of walking time to a stop, waiting time at the stop, in-vehicle travelling time, and waiting time at any interchange stations. The study of O'Sullivan et al. (2000) on the other hand used a shortest path algorithm to forecast the travel time, and created isochrone maps of travel times. Similarly, Gent and Symonds (2004) suggested to explore the areas that are accessible within a 60 minute travel time. However, almost all of these earlier researches are grounded on the assumption that service frequencies and travel times are constant disregarding the time of the day (as cited in Lei & Church, 2010).

"Integral accessibility" is the third category of accessibility metrics, that enables the measurement of overall access for not a single destination but a number of possible activity spaces. It is achieved by counting the number of activity spaces within a reasonable travel cost in terms of distance or time (Wachs and Kumagai 1973, Talen and Anselin 1998, as cited in Lei & Church, 2010).

The fourth category of accessiblity measures is based on the concept of "Space-Time Geography" (Hagerstrand 1970) as explained above as an approach to measure accessibility in general. It based on the assumption that participating to activities in different locations is limited by time budget and requires time/space convergance (as cited in Lei & Church, 2010).

Use of the "utility theory" constitutes the fifth category of accessibility measures and assumes the users as rational in choosing the mode to travel from an origin to a destination that maximizes the utility. The so-called utility depends on the attributes of user and transport option such as monetary costs, travel time, comfort, and characteristics of the activity location (Lei & Church, 2010).

The sixth category of accessibility measures is "relative accessibility" depending on the comparison of accessibility provided by modes or to users (Church and Marston 2002 as cited in Lei & Church, 2010). If a consumer has a choice between using a personal vehicle and using public transit in travelling to a destination, the choice is often made as a function of cost, time, convenience and safety. That is, the choice to use transit for many people is based on the relative value of transit as compared to another mode.

In summary, overcoming the space under certain constraints is demonstrated as the ultimate function of transportation service according to the theory of transportation geography. The amount of space that is overcome within a given time is considered as the most basic measure of transportation. It is also a prerequisite for accessibility model, which is simply defined as the measure of the ability of a location to be reached. Transportation activities are eventually for overcoming space so that urban activity locations become "accessible" by users within particular constraints. So, the quantity and quality of service provided by a given transportation system determine how much the serviced area/geography is accessible by the users. There are many researches on the aspects of integrated multi-modal transportation and its impacts on ridership of a given network. Some particular keywords about integrated multi-modal transportation and its dimensions are attained from the related literature.

“Seamless operation” and “direct travel” are the two key concerns of integrated transport whereas “walking time”, “waiting time” and “distribution of travel times” are commonly identified as main components of “transfer penalty” referring to cost of travellimg with transfers. It is also concluded that there is a broader motive for potential users to rationally decide whether an integrated multi-modal transit system requiring transfers provide a “benefit” to them. The role of integrated multi-modal transit systems therefore is to benefit the users by enabling the desired “access” to various destinations in space despite the physical and operational limitations. This point of view will be constituting the approach of this study to evaluating the integration performanse of the case PT system.

CHAPTER 3

URBAN RAIL-BUS INTEGRATION IN CASE CITIES

The Canton of Zürich and Melbourne Metropolitan Area are the cases that will be elaborated throughout the research. The method of analyzing the cases is best described under three phases: First; comprehending the socio-economic and spatial conditions of research unit. Second; associating the case to the research question through compiling its related experiences. Finally; obtaining concrete values on real life experiences in selected case cities. The dimensions and some of their indicators to be investigated under these three phases are as follow:

- Identity (location, size, economic wealth)
- Urban development (urban form, population density, distribution of land use types)
- Travel choices (car ownership rate, modal split, trip generation rate)
- Transport Policies and Related Researches (clues for attmepts to improve the integration and its positive impacts or clues for poor integration conditions and its negative impacts)
- Transportation Network Characteristics (PT network, operating system, timetabling, ticketing)
- Identification of Case Line and Stations (train route, length, service area of metro stations and connected busses, ticketing, timetabling, station specific identifications, access time and distance to the stations)

Considering the last step, corresponding to the phase of obtaining concrete values on real life experiences in case cities, the case lines are selected based on several factors. The most important of these are their length from the city center, the land-use pattern and thirdly the population density around the lines. It is because chosing the case

lines similar to Ankara in terms of land-use and population density of serviced area and length makes them comparable in terms of integration characteristics.

Having described the selected train lines in the case cities, characteristics of bus services for transporting citizens from other parts of the settlement area to the bus stops for transferring to train stations are explored on hypothetic trips for each bus lines connected to train as sample. The determined criteria in this context are minimum, maximum, and average access time and distance to the station, and service frequency of both busses and trains –intervals-. For exploring these factors, ideal routes from the bus stops with maximum distance and medium distance to the connected train stations at morning peak hours on working days are queried through online information systems. Querying for access from selected point to station, the system reveals the ideal transit connection option and gives the waiting time for both bus and train service as well as in-vehicle travel times. In addition to travel distance and travel times, the maximum distance serviced by feeder bus routes and its ratio to the driving distance of the same route are obtained in order to analyse how directly or indirectly the bus lines connect neighborhoods to train stations.

3.1 Zürich

3.1.1 Identity

Zurich, one of the 26 cantons of Switzerland, is located in the northern east part of Switzerland. Canton in Switzerland stands for territorial sub-division established for political and/or administrative purposes, the boundary of which is mostly coincided with settlement pattern. There are two reasons for selecting “canton” as the unit of settlement to be investigated. Firstly, it is the best equivilant of Ankara Greater City Area in terms of the size and population of settlements in Switzerland. Secondly, most of the required data is available in the scale of either canton or urban cores.

Figure 3.1 Map of Zürich

Source: (http://mapsof.net/switzerland/map-of-canton-zurich)

According to the data revealed by the Federal Statistical Office (2012), Zurich cantonal area of approximately 1729 km² is made up of the City of Zurich and 130 other municipalities. It is the most populated canton with its population of approximately 1.5 million people in 2017 and with over 900 inhabitants per square kilometer (Federal Statistical Office, 2017).

In addition to being the economic engine, Zurich, for years, has occupied top ratings in concultancy Mercer's evaluation of life in 215 cities around the world each year (Kanton Zürich, 2019). These key features of Zurich are given so that the conditions in which the public transportation facilities and use are investigated could be better comprehended and comparison of these facilities with those in Ankara could be realistic.

3.1.2 Urban Development

Urban density and urban form are another essential factors to be investigated for understanding the level and type of public transportation services. It is also needed for explaining the similarities and differences of two or more cities to be compared in terms of public transportation services. It is basically because the density of people in a certain place within a city and their potential origins & destinations and travel routes are directly determined by urban form and planning decisions allocating land uses/activity places and population density. Therefore, attributes such as urban form, population density, distribution of land use types are to be figured out before exploring use of public transportation.

The map on the Figure 3.2 shows the basic categories of land uses in Zurich settlement area. It is observed that the form of urban agglomeration is mainly constituted by a central area which is city of Zurich, and adjacent development corridors along radiants to the west, north, and south-east. The west radiant is composed of high-density mix-use and industrial zones along a corridor, and medium-density residential zones with one or two storeys behind them. The north radiant similarly is settled mostly by high-density mix zones surrounded by residential zones. However, there is also a formation of another urban corridor in soth-east direction attached to the north radiant. This formation comprises high-density industrial zones and three or more storey residential areas near to attachement area. The two development radiants to direction of South-East along Lake Zurich have some differences than the others. Firstly, the central functions and density are

not homogenously allocated along a corridor. Rather, mix use areas are arranged in clusters at certain distances on the corridor. These might well be identified as sub-centers around which medium and low density residential zones have developed. As the sub-centers and their hinterlands have grown, the settlement has got a corridor form along which the activity areas are not alligned but clustered. Another difference is that there is no residential zone with three or more storey in these corridors, and therefore the residential density in the corridors along Lake Zürich is lower and more dispersed than the density in other parts.

Having corridor type of development directions from central area, the form of urban agglomeration of Cantonal Zurich well corresponds to radial city. In addition to the radiants originated from the central city, there are also settlement area of Winterhur -the second largest city within the Canton- almost 20 km away from the center, and several small settlement areas with individual sub-centers. The map also illustrates how far the radiants and spatially independent settlement areas are dispersed from the center in order to have a better understanding of cantonal scale. The first ring exhibits the areas with 10 kilometer while the second ring covers 20 kilometer distance from the Zurich central city. Accordingly, the radiants to the north and west are dispersed almost 10 km whereas radial developments to South-East along Lake Zurich have exceeds 20 km from the center.

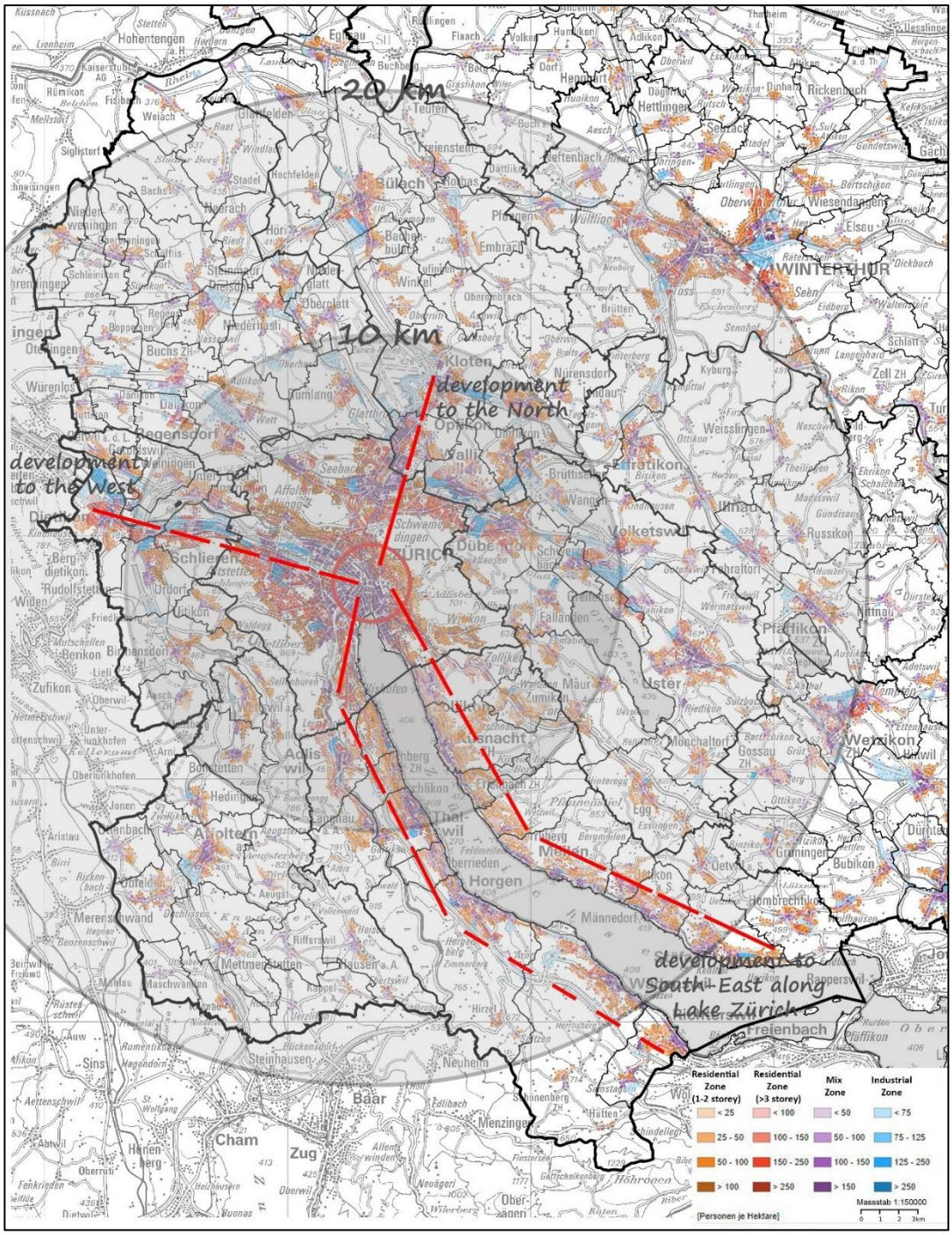


Figure 3.2 Map of Urban Development in Zürich

Source: Produced by the author based on data sourced by Kanton Zürich GIS-Browser

Construction years of the building blocks are presented in Figure 3.3. The darkest blue marks illustrates the building stock that is constructed before 1850. The year of contruction gets closer to 1950s and turns to green when corresponds to construction years of 1961-1970. Finally, the yellow marks represents the building that are constructed after 2000. The whole figure exhibits that there were only the city of Zurich almost with the same size but lower density, much more smaller size city of Winterhur and other settlements scattered within the Canton and especially along the Lake Zurich in south-east direction in 1950s. There was no indication of any of the radiants present today but the small settlements along the Lake Zurich had been aligned in a row and had formed a direction. After 1960, both the City of Zurich and other settlement areas in the canton have spreaded towards certain directions. Radiants constituting the present urban form began to emerge as a result of such kind of urban development process until 1990s. However, after 1990s, urban development have taken the shape of intensifying and filling the urban gaps rather than constantly spreading away. Regarding the construction activities in post-2010 period, it is possible to conclude that the radiants which have reached 10 km from the center to the north and west, and more than 20 km to the southeast are formed prominently, and urban density is increased in parallel to inward development.

The adaption of inward development strategy is also emphasized by Kanton Zürich (2018). It is determined in the Richyplan individual consumption of living space and that total area consumption increases in many places with the population growth. The further structural development on the green field however is no longer desirable in the Canton. As a result, settlement development is needed to be directed inwards. This means that growth and structural development should take place in the areas that are already mostly developed (Kanton Zürich, 2018). Canton, regions and municipalities are jointly responsible for consistently orienting spatial development towards this objective.

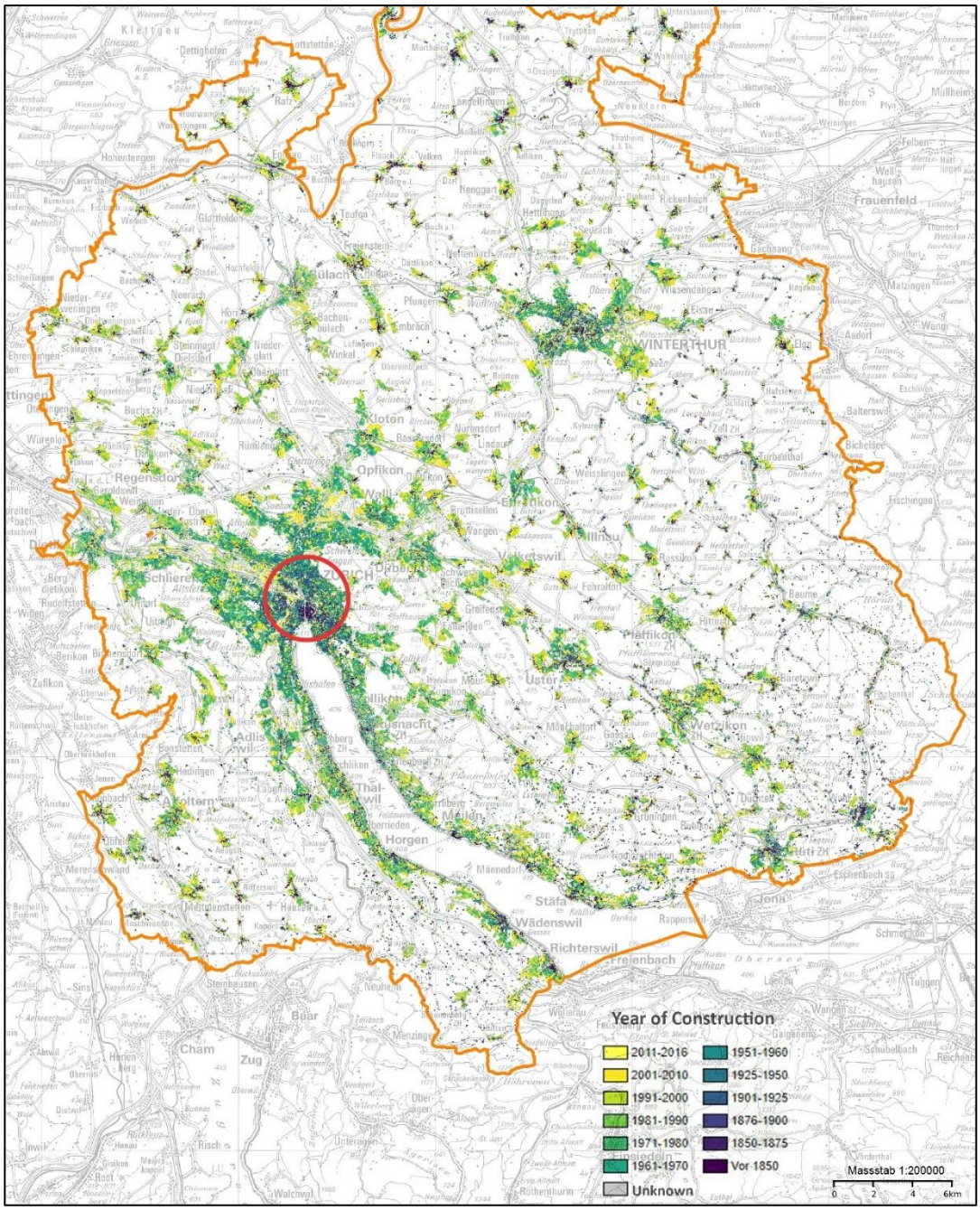


Figure 3.3 Map of Urban Development by Years in Zürich

Source: Produced by the author based on data sourced by Kanton Zürich GIS-Browser

It is already mentioned that Zurich cantonal population has tended to increase since the early 1900s. Figure 3.4 and Figure 3.5 show the population change between 2008 and 2017 both for the Canton and the City based on the official statistics. According to the graphs produced from the official statistics, the population has increased rapidly from 2008 (1128632 people) to 2017 (1504346 people) by approximately 350000 people (3% increasing rate) in 9 years although the rate of increase slowed down after 2010. Besides, 350000 people are almost equivalent to the population of Zurich city center. In the city center, the increase in population -approximately 26600 person corresponding 0.6% increasing rate - was much more lower than in the Canton.

In order to have a better understanding of possible impact of population increase in urban area, it would be useful to explore the graph in Figure 3.5 presenting the change in population density. It is displayed on the graph that 906 people live in one kilometer square area in the Canton in 2017 while there were 827 people living in the same size urban area. That is, population density per km2 have rise as a result of population growth. Not interestingly, it is expected that the number of people using urban activities in a given area, therefore the need for access to activity centers, and the demand for urban transportation will increase. Considering this reality, the extend and quality of urban transportation services in the Zurich Canton, how ownership of private car has changed under these conditions and what are the factors behind these are worth to be investigated.

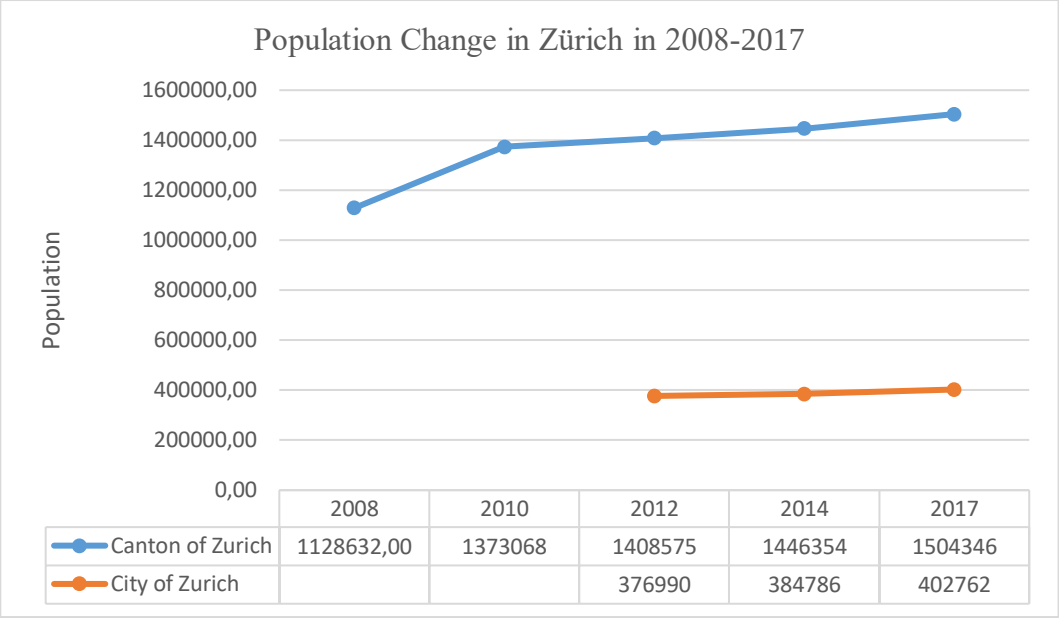


Figure 3.4 Population Change in Zürich

Source: Produced by the author based on data sourced by Federal Statistical Office

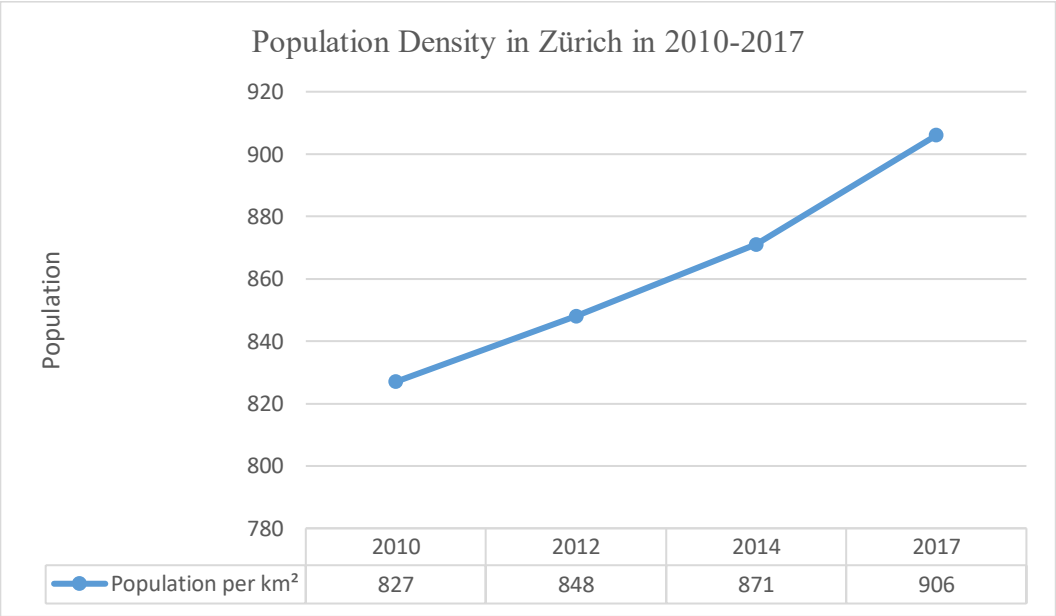


Figure 3.5 Change in Population Density in Zürich

Source: Produced by the author based on data sourced by Federal Statistical Office

3.1.3 Travel Choices

According to data revealed by official site of Zurich Canton, there are 4.19 million journeys within the canton everyday, corresponding 2,7 journeys per person per day. It is a deterministic criteria because it directly affects potential demand for transortation facilities and transportation economies. Car ownership rate and modal share of total trips within a city are considered as other two essential indicators of people's travel choices. Specifically in the context of this thesis, change in car ownership rate and public transportation share in total trips will be decisive in evaluating the cases as either positive or negative experiences for promoting public transportation use.

Figure 3.6 below shows the numbers of cars per thousand residents and illustrates the change in car ownership rate in Zurich from 1999 to 2017 based on the data revealed by Federal Statistical Office. It is presented that car ownership rate has been almost stable from 2012 to 2017 although it had rised from 362 in 1999 to 484 in 2010. Interestingly, either the total population nor the population density have staid stable in the period of 2010-2017. Because the need for transportation activity and consequently the car ownership is expected to increase as population gets larger, there would be particular efforts to promote alternative transportation choices through strategies and policies.

In parallel to previous graph, Figure 3.7 indicates that public transportation share in all trips has risen from 37% in 2010 to 45% in 2014 and to 46% in 2017. Whereas, share of private car use has slightly felt from 42% in 201o to 41% in 2017 even though much of the increase in PT share seems to be compensated by the fall in the share of foot & cycle. Thus, the inference that alternative choices would be particularly promoted in order to cutting the increase of private car use is confirmed by data showing the change trend in modal share of total trips.

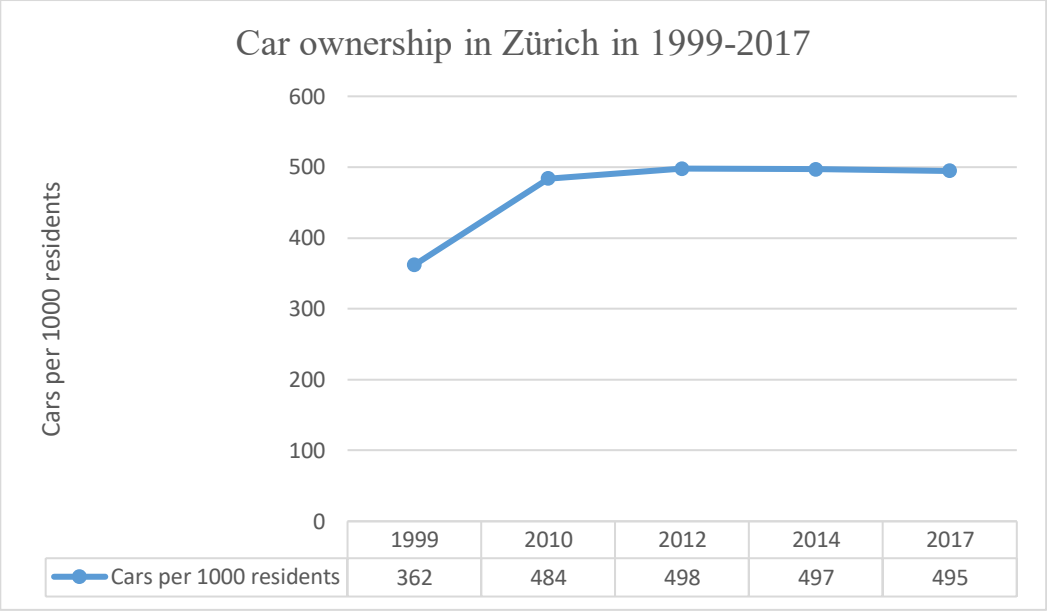


Figure 3.6 Change in Car Ownership Rate in Zürich

Source: Produced by the author based on data sourced by Federal Statistical Office

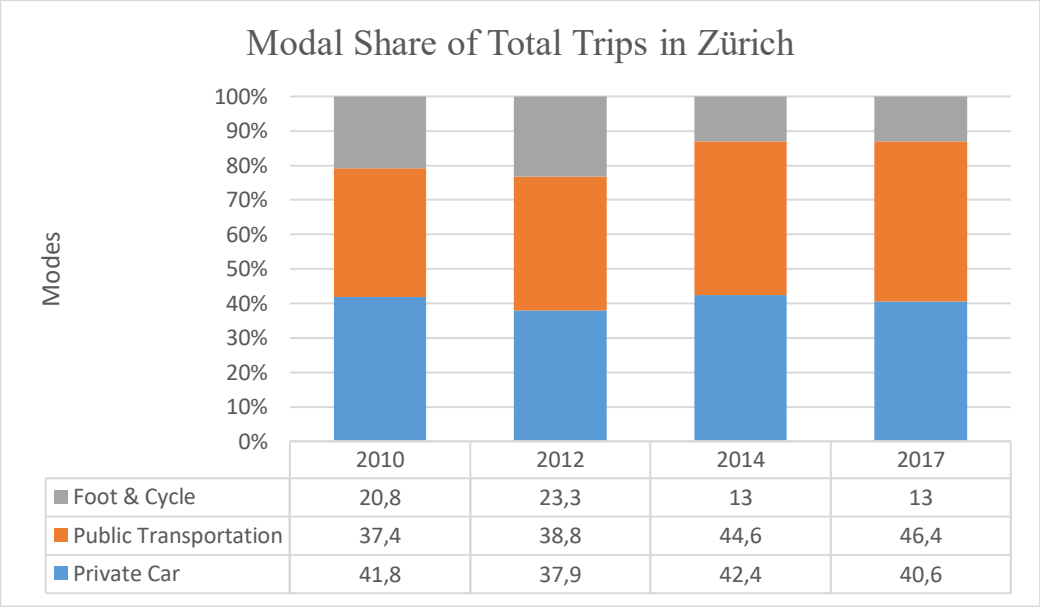


Figure 3.7 Change in Modal Share of Total Trips in Zürich

Source: Produced by the author based on data sourced by Federal Statistical Office

In summary, the Canton of Zurich with the highest GDP in Switzerland has a significantly high level of economic development, which is particularly advanced at finance, information technologies, and business. It is indicated that one of the major pillars of this level of economic development is well developed transportation links at both national and regional scale. Despite the general perception that vehicle ownership and the related infrastructure is always at high levels in developed economies, enpowerment of public transortation network and success for promoting citizens to use public transport are the keys for considering Zurich as an example within the scope of this study. Furthermore, in accordance with the transportation policies and research results described in following section, there will be a search for whether the integration level and form of different modes in Zurich public transport network positively affect the use of public transport at cantonal and urban levels.

3.1.4 Transport Policies and Related Research Results

The common emphasis in most of the written documents on Zurich's transport policies is that the year 1980 was a milestone. After the public takeover of transport policies in 1980s, a radical priority programme has been implemented in Zurich transportation strategies including upgrading the existing tram, trolley-bus, and bus system with exclusive lanes, priority at intersections, and higher frequencies. Mees (2010) in his study widely adverts that PT patronage in Zurich increased by about half until 1980s as a result of adopting an explicit policy of giving priority to PT in allocation of funding and roadspace.

There are many essential steps that Zurich has taken in accordance to priority programme for public transportation. But the most crucial moves could be considered as formation of regional commuter railroad and followingly establihment of Zuricher Verkersvenbund (ZVV), a regional agency responsible for coordinating fares and schedules of more than 40 different transport operators (Nash, 2001). In this way, it is widely regarded that operations at different levels proceed smoothly, timetables are maintained and budget guidelines are observed. Subordinate to these

companies are small and medium-sized transport businesses with concessions and transport service providers that are primarily responsible for providing services on specific routes. This organizational form, whereby strategic and operational tasks are separated, has proved to be economically viable, efficient and customer friendly.

Zurich has implemented three complementary programs that helped support the city's transit system. As Nash (2001) explaines in his study, firstly it is learned that planning land uses is one of the essential complementary programs to promote transit system. Zürich has worked aggressively to encourage land uses that support transit. It accomplished this through conventional land use planning techniques such as zoning and development agreements, as well as by making the areas best served by transit attractive places to live, work, and visit. Second, explained by Nash (2010) is that reducing traffic volumes is considered factor promoting transit sytem use. Zürich used three main approaches to control the vehicle traffic in the city: traffic calming, reduction of roadway capacity, and parking controls. As with other programs, Zürich has taken a comprehensive and thoughtful approach to controlling vehicle traffic. While activists argue that there is still too much traffic in the city, the government would say that there is less than there would have been without these programs. Third, a regional transit coordination system is a must for well-developed transit network. The Canton of Zürich organized the Züricher Verkehrsverbund (ZVV) to coordinate fares and schedules for the region's 42 different transit operators. Today it is possible to use a single ticket on all these systems, and careful scheduling links them. The canton also built a regional fast suburban rail system (S-Bahn) that provides regional mobility and serves as the basis for schedule coordination. Good regional transit has increased ridership on Zürich's city transit system and provides an argument for reducing traffic volumes on major routes into the city (Nash, 2001).

In addition to the cantonal organizaton of public tranport operations, municipalities under the Canton also integrates their strategies to Cantonal network. The city of Zürich promotes a modern public transport network which branches out far and wide: trams, buses, ferries, suburb trains and funiculars combine to make up a

comprehensive and efficient range of transport options, functioning as a part of the cantonal network. Consequently, the tram and bus networks provide shorter intermediate-length trips whereas longer intermediate-length trips are made on the S-Bahn network, alleviating the need for an intermediate, third-level system - a subway or Metro system.

The Canton of Zurich, which had taken crucial steps for integrating modes of public transportation at different level and promoting public transportation use, puts the subject further by including not only vehicle based modes of public transportation but also walking, cycling, and their integration to the overall network. Zurich's Transport Plan 2025 has set a clear affirmation for walking, cycling, PT and against car traffic by increasing the modal split and improving attractiveness of PT (Stadt Zürich, 2014). Therefore, cycling and walking promotion is considered essential for Zurich in 2025. The Cantonal Council has set a clear example for bicycle promotion in the canton with the cycle promotion program: a framework loan of 20 million for ten years. The aim is to increase the share of bicycle traffic in total traffic. On 1 February 2012, the Coordination Office for Cycling as the cantonal focal point for all questions relating to bicycle traffic began operations. In parallel, Zurich also has the official goal to reduce energy consumption to 2000 watts per person related to all energy consumption sectors, including transport (PASTA, 2017)

The main concern when searching the transport strategies and related research results for Zurich is to answer whether they have positive impact on high PT use. Mees (2010) in his study have tried to exhibit the reasons for PT use in Zurich so much higher than other central cities in Switzerland and Europe. The two major reasons he put forward was directly related with some different dimensions of integration. Firstly, he asserts that the critical factor is the way ZVV functions as an integrated network. Secondly, Zurich has avoided two estremes, many of similar cities have mostly tackled. That is, many cities that built metros have concentrated high service levels on the metro lines, leaving passengers wishing to reach locations that are not on the metro with an infrequent and unattractive service. Zurich on the contrary, offers high frequencies and reliable services on all corridors with multi-modal fares,

and easing transfers between routes. Bus routes serving suburban areas terminate at tram interchanges and do not enter city center. Economical densities of patronage allow trams to cross-subsidize busses as well as keeping the city center free from congestion of busses.

3.1.5 Identification of Case Line and Stations

This part of the study on Zurich case will focus on the selection of a transit radiant on the network and spatial analysis of its connections to the bus lines in order to determine the characteristics comparable to Ankara case.

The selected route in Zurich transit network is the southeast axis of sub-urban rail system, along to the Zurich Sea, S-bahn. There are several factors for choosing this axis to be determined. The most important of these is that it is the most similar to Ankara case in terms of its length from the city center. Secondly the land-use pattern and thirdly the population density around this line is also similar to those in Ankara example, which makes them comparable in terms of integration characteristics.

The selected axis within the overall frame of regional transit network and urban corridor along the axis are illustrated in Figure 3.8 below. It is seen on the map that there are more than one S-bahn routes on the same axis. These are S6, S7, S16, and S20, each of which has different start and end point, and different schedules. This means that there are operational strategies for providing the best-fit but also efficient service for a given area. The line to be investigated is S6 because it is the one with medium-length and has no express service like S7. The form of the corridor is linear consisting of low and medium-density residential areas in mostly, a little industrial areas and mix zones. The overall length of development corridor is approximately 28 km which well corresponds to the length of S7. However, the selected line (S6) is at approximately 17 km away from the city center that is very similar to Ankara case.

There are several settlements serviced either directly by S6 line or by busses providing connections to it. Considering the district of Zurich (the city itself) as the starting point, there are settlements of Zollikon, Küshnact, Erlenbach, Herrliberg, Meilen, and Uetikon in sequence. Total population of these settlements is approximately 60.000 excluding the Zurich, and 462.000 including it (Federal Statistical Office, nd). The Figure 3.2 reveals that the population is allocated mostly by medium (50-100 person per hectare) and rarely by medium-low (25-50 person per hectare) and medium-high (100-150 person per hectare) areas. Knowing the population and density along the study area will be useful in comparing characteristics of public transit demand and supply in Zurich and Ankara as well as making proper inferences for Ankara case.

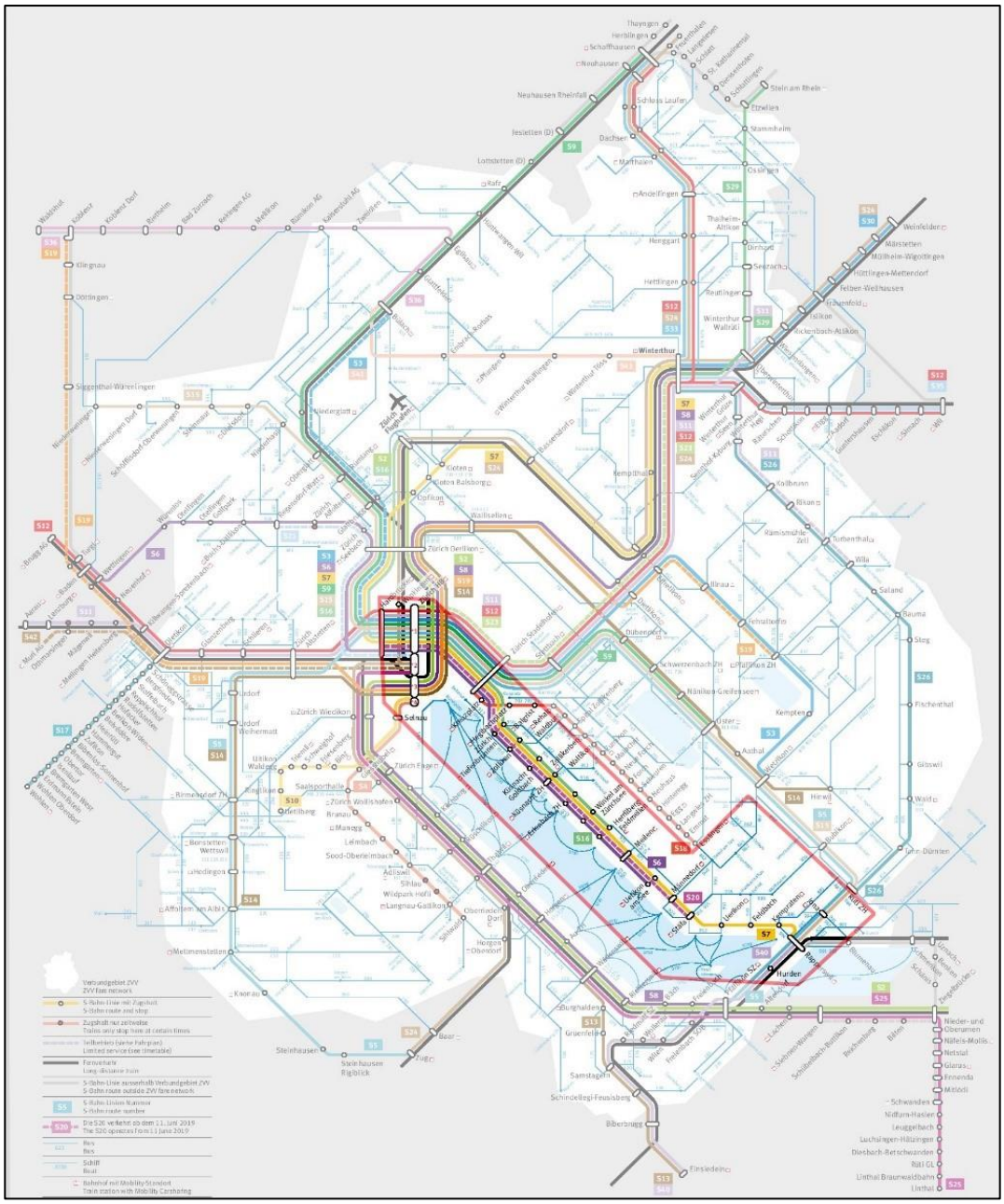


Figure 3.8 Map of Transportation Network in Zürich

Source: Zürcher Verkehrsverbund, 2018a

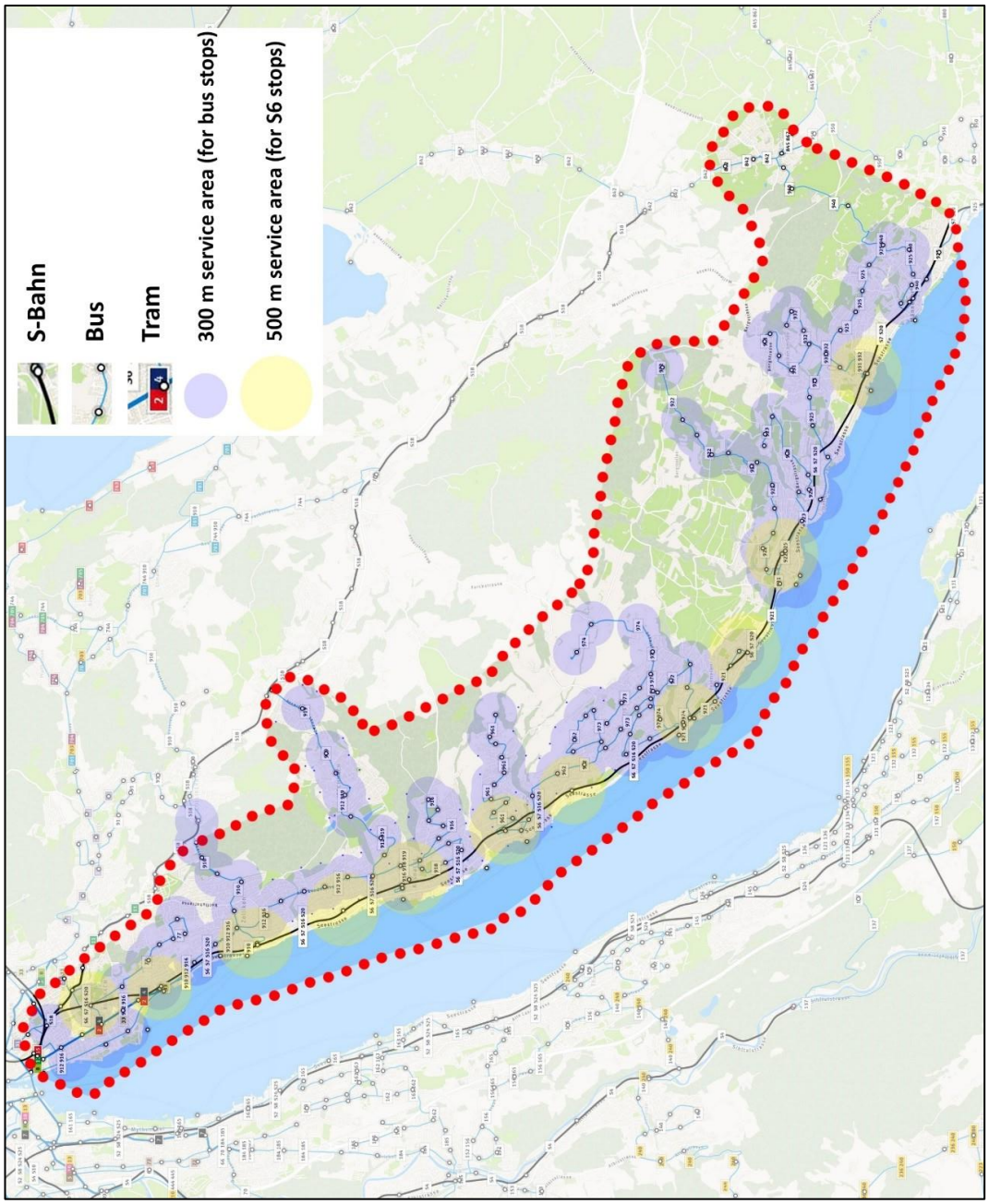


Figure 3.9 Map of S6 Route and Feeder Bus Lines in Zürich

Source: Zürcher Verkehrsverbund, 2018b

Spatial integration of S6 route and all the local bus lines are presented in the map in Figure 3.9. There are also a representation of S6 stations with 500 meters-radius service area and bus stops with 300 meters-radius service area. Accordingly, the average distance between the stations on S6 line is 2 km although the distance between the last two stations, Uetikon and Meilen is 3 km and several stations it is 1 km. Having examined the yellow circles on the map showing 500 meters-radius service area for S6 stations, it is apparent that the line covers very small amount of settlement area it goes through. In other words, almost 20 % of the population can directly benefit from rail service when the S-bahn line is considered as a single tranportation service. However, it is observed from the map that the total service area is almost quadrupled when considering the bus lines connected to the S-bahn.

Considering the access area within a radius of 300 meters of all bus stops, it is seen that almost the entire population is covered either directly or indirectly by rail service. This means that almost every household has access to the S6 at a maximum distance of 300 meters, which is a very large amount of coverage in a quite short distance.

The farthest location connected to the rail line by bus service is aproximately at 6 km distance to the station, which is accessed in 15 minutes. Moreover, the average distance to the station is 2,2 km and average access time is 7,7 minutes considering the randomly selected addresses and travel directions proposed by online trip planner available on official website. The travel distances and times to reach the rail stations by feeder busses in Zürich are assumed as good standards because the use of public transport has been increasing despite the economic wealth and its multimodal integration in public transit is widely commended.

As a result, it is determined that the case line in Zurich, the S6 route, is very limited in terms of direct access to the stations but is indirectly available at most 300 meters distance to the whole population along the line when integrated local bus services. Thereby, a considerable part of spatial integration of train-bus transit systems is realized. In addition to the direct service area of the rail transit, indirect service area

provided by bus integration and transfer facilities generate an overall coverage as a result of which the principles of scope economies comes into agenda. Similarly, the Zurich transit sytem considers the travel between particular origin and destination as a single transportation service and does not require multiple payment for each vehicles for the journey. This prevents the passengers from considering the journeys that require transfers as extra costs and makes the system a complete network by allocating the overall transit profit to all operators by the ratio of services offered.

Following the spatial and ticketing integration, the case station on the line are selected in order to examine the further criteria for multimodal transport integration previously underlined in the literature review part. These stations are not selected randomly but depending on two important criteria. The first is that these two stations are the major transfer points from train to train and from bus to train on the line. Hence, the integration facilities can be best observed at these stations. The second is that they are the two biggest settlements on the line in terms of population and urban settlement area.

The stations are to be investigated primarily in terms of site selection within the urban settlement area and access conditions from the surrounding land uses to the stations. Followingly, the service factors - such as passenger volume, transfer type, intervals, waiting times, etc- of transfer dependent transportation service offered at the station, an then the station facilities such as availability of passenger information systems, safety, comfort, accessibility, typology of platforms will be examined.

3.1.5.1 Küsnacht Station and Bus Lines

The characteristics of bus services for transporting citizens from other parts of the settlement area to bus stations is explored on three hypothetic trips as sample. The determined criteria in this context are minimum, maximum, and average access time and distance to the station, and service frequency of both busses and trains –intervals. For exploring these factors, ideal routes from randomly selected three different

locations with low-medium-and high distances to the station in peak hours on working days are queried through the online route planner available on official website of ZVV (2018b).

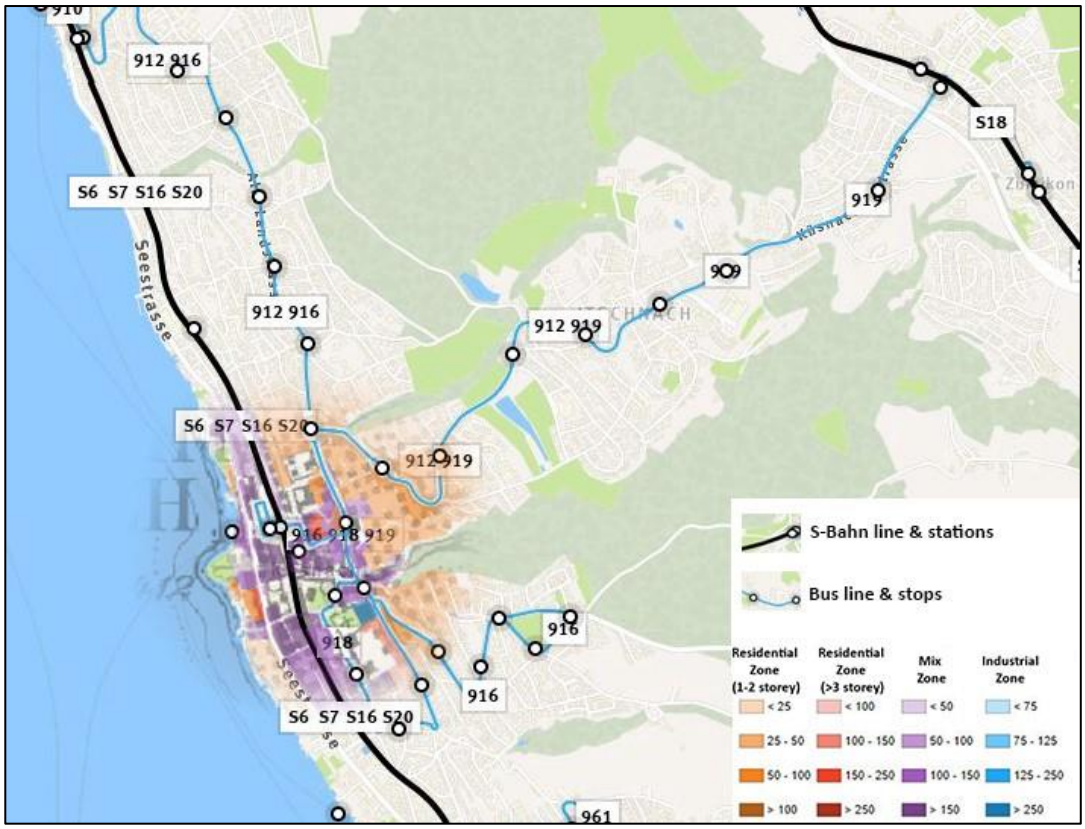


Figure 3.10 Küsnacht Station and Feeder Bus Lines

Source: Zürcher Verkehrsverbund, 2018b

The first point selected to be explored is the adress of Küsnachterstrasse 9, presented in the map below. It is firstly required to reach the nearest stop of bus line 919 by walking approximately 5 minutes in order to access from this point to the station. There is no waiting time at the bus stop because the online information system proposes the appropriate time to leave the origin according to the bus schedules. Having approximately 12-minutes journey by bus, it is arrived at Küsnacht Bahnhof stop. Then, the platform 3 is reached after having approximately 3-minutes walking

on the pedestrian route. So, the station can be reached by a 20-minute journey from approximately 5 km distance which is the farthest point servicing from the station. A total of 12-mins of this journey is the bus ride and the rest is a pedestrian trip. The waiting time for the train at the station is 5 minutes for this example.

The second hypothetic location is the address of Weinmanngrasse 113 in the Itschnach district. The possible connections from this poin to Tiefenbrunnen on the Zürich direction through S6 is queried. According to results of online information system, Rebweg station on the bus line 919 could be reached by a 6-minutes walking. The bus is taken without any waiting at the stop and it is left at Küsnacht Bahnhof stop coded by (2) on the map after having a 8-minutes journey. There is a 3-minutes walking to reach platform 3 to get S6 train and approximately 5 minutes waiting for the train. The whole journey from a point with 3 km distance to the station takes 17 minutes, 8 minutes of which is on bus and the rest is pedestrian trip.

The third location is the address of Alte Landstrasse 126, which is relatively nearer –with 1 km distance- to the station than the others. The bus 919 is taken after having a 2-minutes walking from this point. Zürich Bahnhof stop is reached through a 4-minutes bus trip. Finally a 3-minutes walking is required in order to access to boarding platforms. There is also a 1-minute waiting time for train at station after a 10-minutes trip in total.

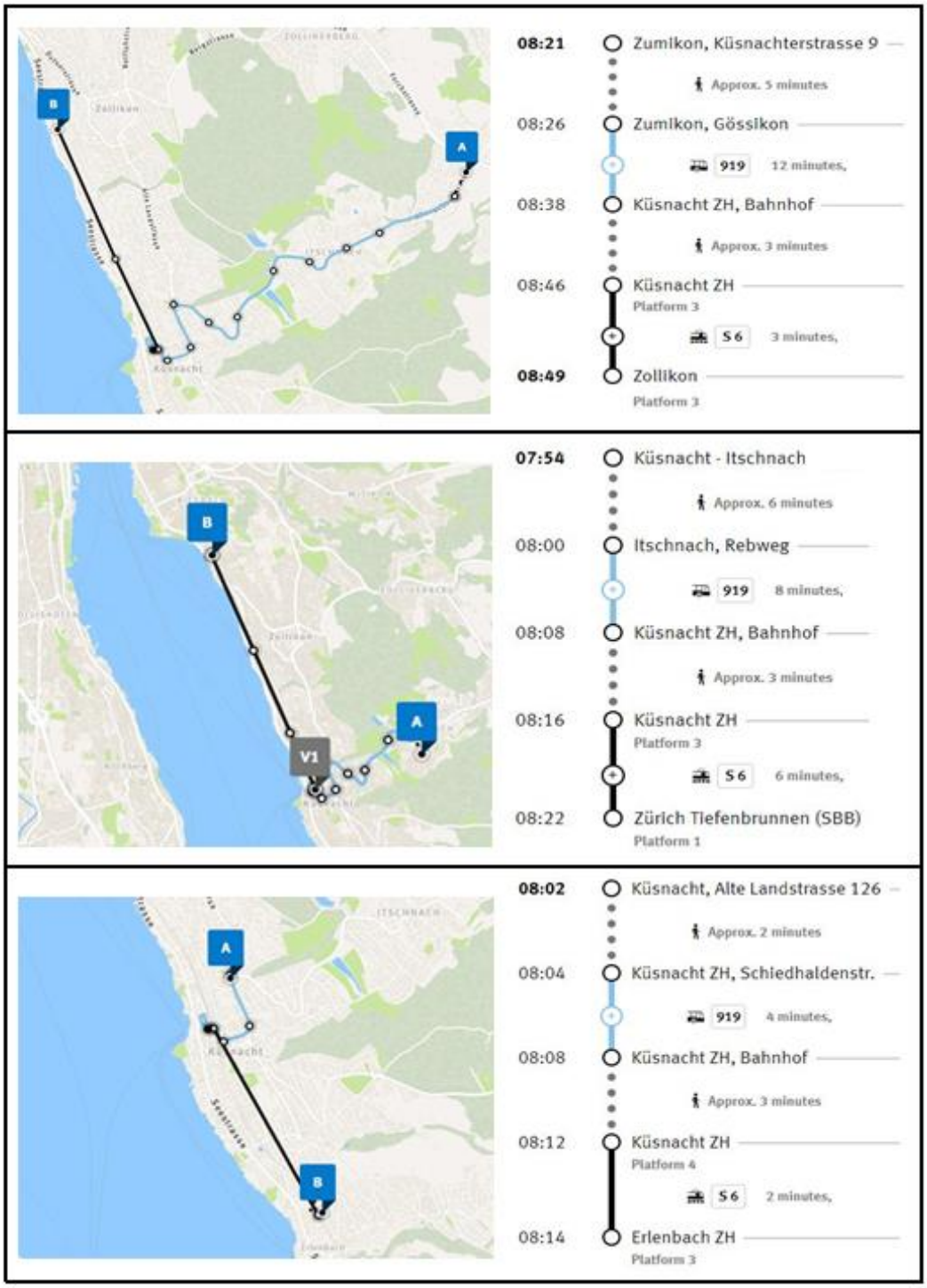


Figure 3.11 Travel Options from Bus Stops at Min-Med-Max Distances to Küsnacht Station

Source: Zürcher Verkehrsverbund, 2018b

3.1.5.2 Meilen Station and Bus Lines

Figure 3.12 Map of Meilen Station and Feeder Bus Lines

Source: Zürcher Verkehrsverbund, 2018b

For exploring the characteristics of bus services via the factors such as minimum, maximum and average access time and distance to the station and service frequency, three point serviced by the station are selected randomly. The first point selected to be explored is the adress of Herrenbeg 600, presented in the map below. It is firstly required to get the bus 922 through the nearest stop reached by a 3-minutes walking. There is no waiting time at the bus stop because the online information system proposes the appropriate time to leave the origin according to the bus schedules. Having approximately 14-minutes journey by bus, it is arrived at Meilen Bahnhof stop. Then, the platform 2 is reached after having approximately 2-minutes walking

on the pedestrian route coded (1) on the map above. So, the station can be reached by a 19-minute journey from approximately 5 km distance which is the farthest point serviced by the station. A total of 14-mins of this journey is the bus ride and the rest is a pedestrian trip. The waiting time for the train at the station is 5 minutes for this example.

The second location is the address of Weingartenstrasse 21, which is approximately at 3 km distance to the station. The bus 925 is taken after having a 4-minutes walking from this point. Meilen Bahnhof stop is reached through a 11-minutes bus trip. Finally a 2-minutes walking is required in order to access to boarding platforms. There is also a 6-minute waiting for train at station after a 17-minutes trip in total

The third hypothetic location is the address of Schulhaus Obermeilen. The possible connections from this point to Küsnacht ZH on the Zürich direction through S6 is queried. According to results of online information system, the bus 923 is taken without any waiting at the stop and it is left at Meilen Bahnhof stop after having a 3-minutes journey. There is a 2-minutes walking to reach platform 2 to get S6 train and approximately 9 minutes waiting for the train. The whole journey from a point with 1 km distance to the station takes 5 minutes excluding the waiting time at station.

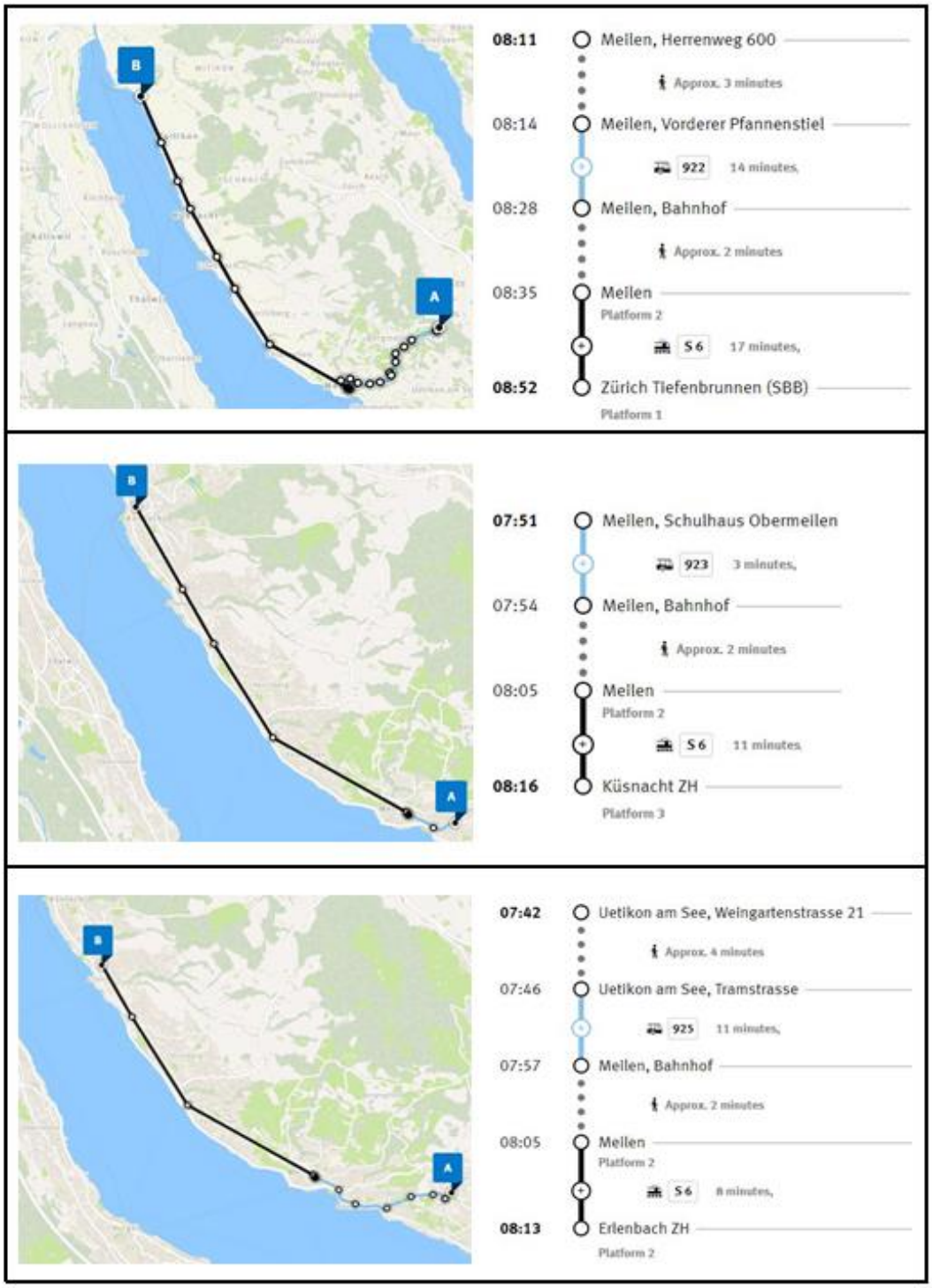


Figure 3.13 Travel Options from Bus Stops at Min-Med-Max Distances to Meilen Station

Source: Zürcher Verkehrsverbund, 2018b

3.2 Melbourne

3.2.1 Identitiy

Melbourne, the capital of Victoria, is Australia's second largest city and located in south-east part of Australia. The greater Melbourne with area of approximately 9900 km² includes the central city of Melbourne and innermost suburbs-the municipalities. It has a 4.9 million population approximately 170.000 of which is in the central city corresponding to density of 495 people per km² according to the data announced by Australian Breu of statistics in 2018. The unit of settlement to be examined in the context of this study is Greater Melbourne metropolitan area because it is the best equivilant of Ankara Greater Area in terms of the size and population as well as the scale of transit network.

Melbourne, as the metropolitan area, contributed 19% to national GDP growth in 2018-2019, which was the largest contribution of all regions across Australia and the highest on record for Melbourne (SGS Economics & Planning, 2018, p.10). As well as being territorial division where the highest part of the economic activities in Australia is concentrated, Melbourne currently occupies third place in the global liveability ranking published annually by the Economist Intelligence Unit (EIU, 2009). These key features of size, wealth and livability will be appreciated when comparing the public transportation facilities and its modal shares in Melbourne and Ankara.

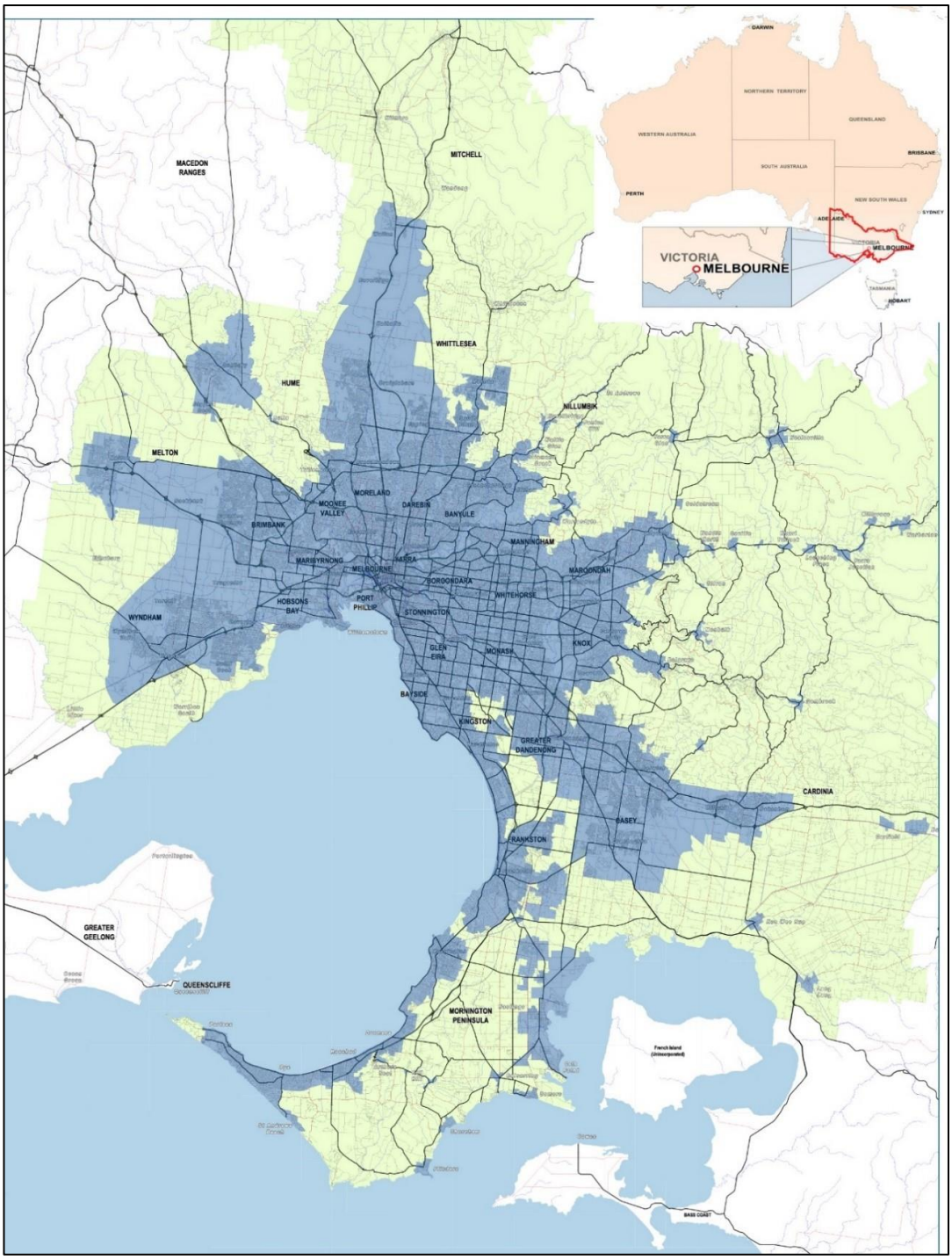


Figure 3.14 Map of Melbourne

Source: State Revenue Office Victoria, 2018

3.2.2 Urban Development

Urban development pattern of Melbourne is described by Kenworthy and Laube (2001) as a sprawling, low-density city by world standards. Moreover, high rates of population and employment growth in Melbourne in the las decades is accomodated by urban expansion as well as intensification of inner urban areas (as cited in Scheurer, 2009).

The map in Figure 3.15 below shows regional urban macrofom and basic land categories in Melbourne Metropolitan Area. It is observed on the map that the metropolitan area with approximately 9900 km^2 is concentrated around the central city of Melbourne and has urban areas sprawling from the center. Metropolitan Melbourne has a network of activity centres mainly in three different scales: Metropolitan Activity Centres, Major Activity Centres and Neighbourhood Activity Centres. Regarding the activity centers as keystones, development axes radiates from the center and connect activity centers through linear development along the radiants. The macroform of Melbourne metropolitan area as such could be well appreciated as a finger or radial plan although it is more likely to be the latter. The metropolitan area has been spreading on these radiants. The base map below which is obtained from the Melbourne plan for the year 2050 shows that there are future growth areas proposed further on the radiants.

Considering how much distant radiants have reached from the center, it could be well comprehended how large the Metropolitan area is. The farthest metropolitan activity centers, Frankston and Fountain Gate-Narre Warren, are 40 km away from the center settlement area around which even exceeds 40 km. Most of the other metropolitan activity centers are within the 20 km radius of the center but development corridors radiating through these centers exceed the 20 km. Thus, urban sprawl along such distances arouses curiosity about urban transport behaviors in such a wide but single urban area as 40 km.

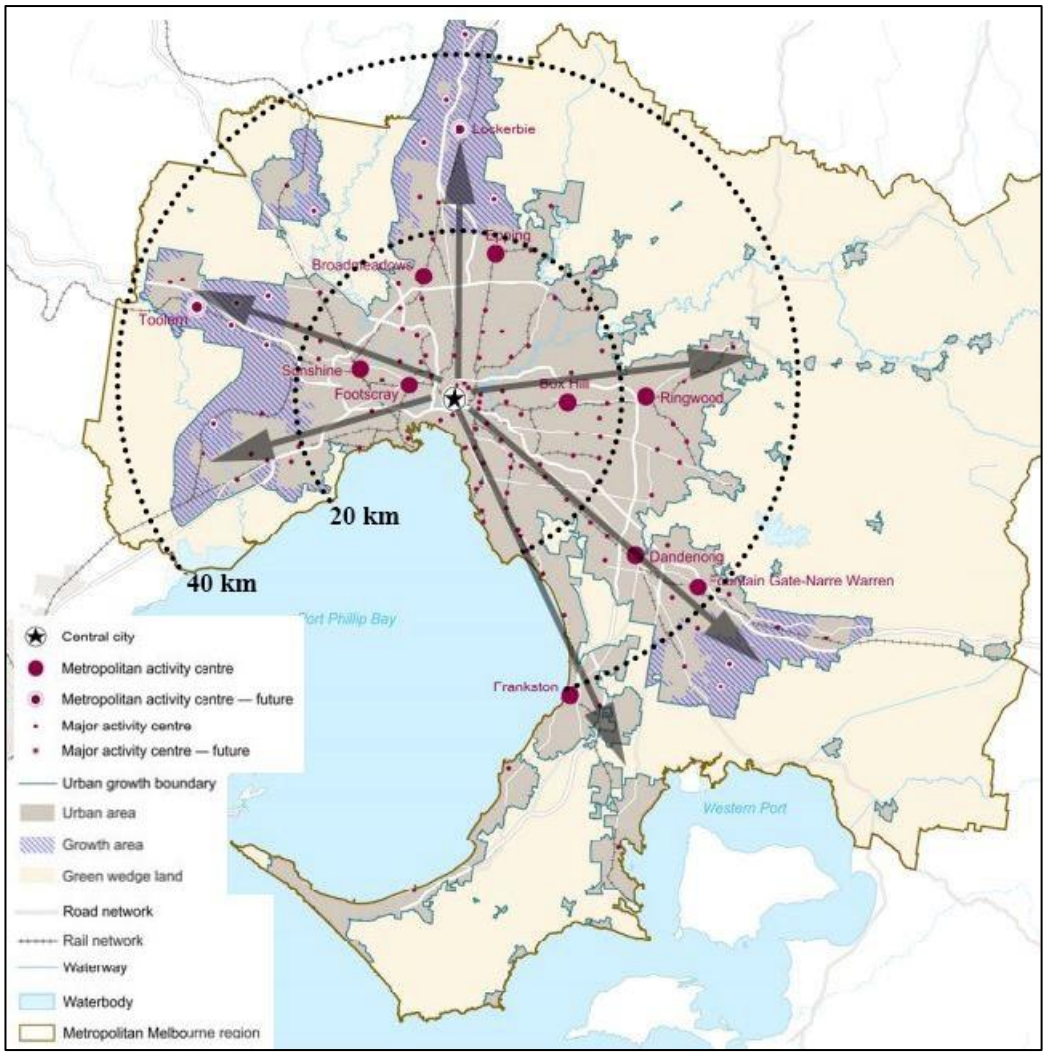


Figure 3.15 Map of Urban Development in Melbourne

Source: Produced by the author based on the map sourced by The State of Victoria, 2017

In addition to the spatial development, changes in the population density in terms of person per hectare are shown on the map in Figure 3.16. Accordingly, the highest density presented on the map is 200-300 person per hectare which only exists in a very limited area in the center. The central city commonly has a density of 60-150 person per hectare but it falls below 60 person and then below 30 person per hectare in the adjacent suburban areas especially in the east and southeast parts. At the

farthest parts of the current settlement area, the density is approximately 5-10 person per hectare which is very low for ensuring efficient delivery of urban services.

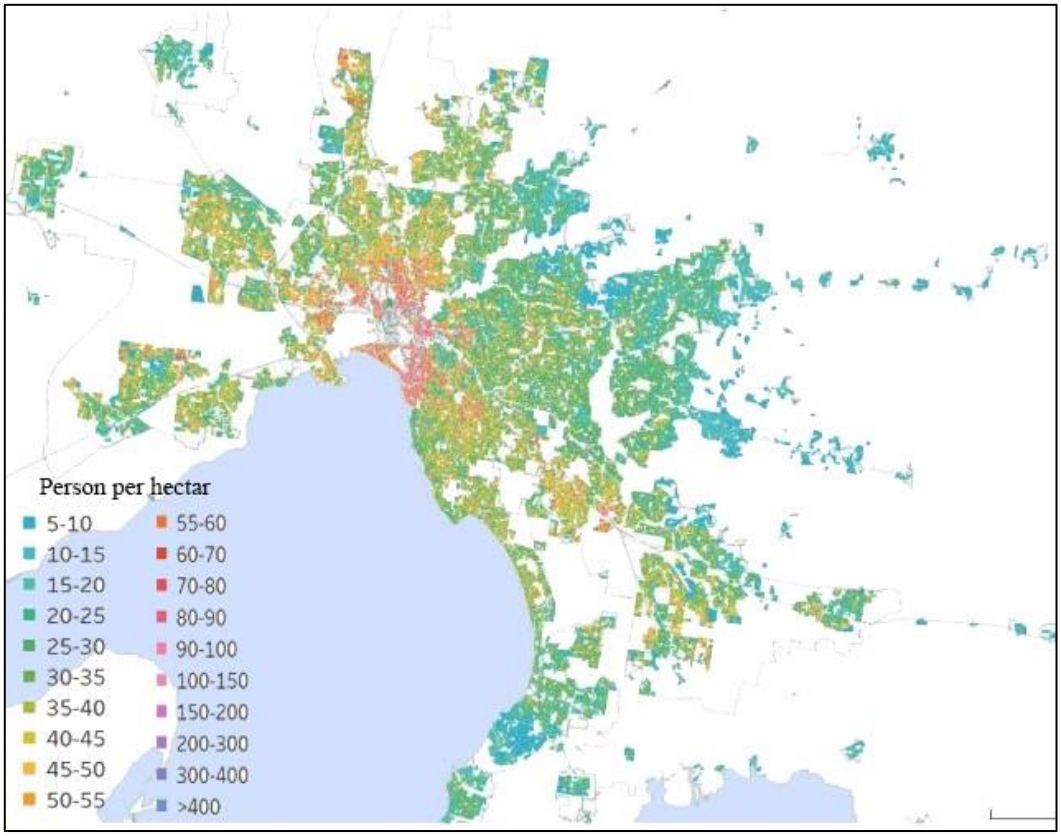


Figure 3.16 Map of Urban Density in Melbourne

Source: Produced by the author based on data sourced by The State of Victoria, 2017

Victoria State Government (2017) explains the breaking points in urban development histroy presented above. It asserts that the expansion that Melbourne experienced in the late 19th and early 20th centuries was a result of development of mass-transit and tram system along the metropolitan area of that period. Mechanised transport allowed Melburnians to leave the highly congested city centre and to settle in suburbs as many European cities. This breaking point could well correspond to transition from the first phase of macroform presented in dark purple to the second phase presented by purple, where the total area was almost doubled. The next wave

of major growth came after the Second World War between 1947-1966 and the population rised by 83 % which is the biggest growth since the Gold Rush –city's population triple between 1851-1890 (Victoria State Government, 2017).

The changes in the urban macroform could not be considered independently of transportation strategies and characteristics of public transport network. It is concluded that there are two factors effective in breaking points in the Melbourne macroform, one which inevitably is economic conditions while the other is investments is transportation and infrastructure. The first breaking change in the macroform development in the form of radiants was concurrent with development of mass transit on the linear axises. The second –which occured in the form of rapid suburbanization- coinsided with large investments in road infrastructure and accompanied rise in car ownership on the other hand. These major changes in the urban macroform is to be examined in terms of population change in the following part.

The graphs in Figure 3.17 and 3.18 above show the population change between 1950 and 2019 both for the Metropolitan Area and the City. According to the graphs produced from United Nations - World Population Prospects sourced data (2019), the population has increased rapidly from 1950 (1.132.000 people) to 1970 (2.499.000 people) by approximately 1.350.000 people (120% increasing rate) in 20 years . Altough the rate of increase fell between 1970-1990, the population continued to grow rapidly after 1990 and especially after 2010. The density by person per hectare also rises due to the population increase meaning that urban space is used more intensively by the residents.

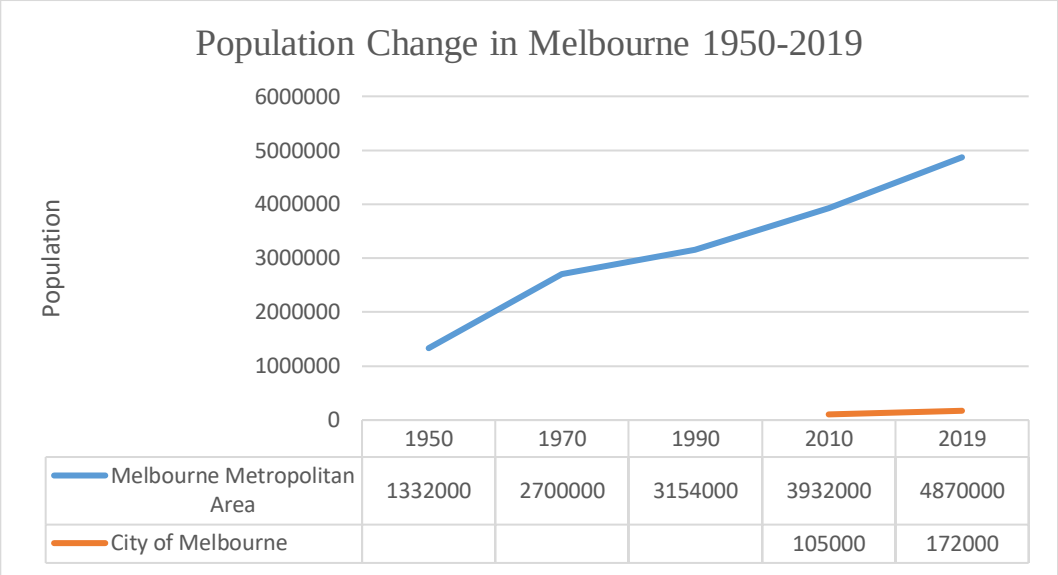


Figure 3.17 Population Change in Melbourne

Source: Produced by the author based on data sourced UN World Population Prospect, 2019

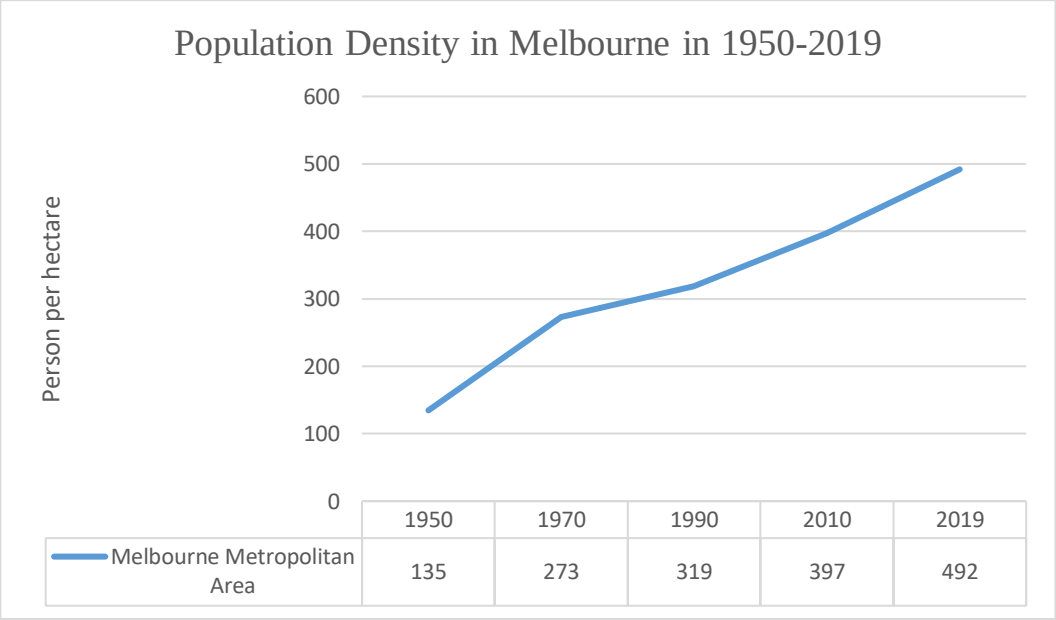


Figure 3.18 Change in Population Density in Melbourne

Source: Produced by the author based on data sourced UN World Population Prospect, 2019

3.2.3 Travel Choices

According to results of Victorian Integrated Survey of Travel and Activity (VISTA), there are 12,3 million trips on an average weekday in 2013 –which is the latest available data (Victoria State Government, 2013, p.2). This corresponds to approximately 2,9 trips per person per day produced within Melbourne Metropolitan area. It is a critical factor in searching for how the different modes of public transportation are organized that all these journeys in that much of sprawled area could be offered.

In addition to the numbers of trip generated in Metropolitan area, the graph in Figure 3.19 shows the change in car ownership rate in Metropolitan area from 1991 to 2016. Regarding the table, the number of cars per thousand resident had continously increased from 480 cars in 1991 to 562 cars in 2011 although the rate of increase fall after 2001. After the year 2011 however, car ownership rate has slightly felt until 2016, which could also be assumed as stable although it is still at a high level. It is highly possible to claim that strategies of inward development have led the high car ownership rate to decrase after 2001 and to stay constant after 2011 although there is no population decrease or economic crisis in the region. So, there would be particular efforts to promote public transportation facilities as an alternative to the use of private car in addition to the strategies of intensification of already existing settlement area.

In parallel with the graph indicating the changes in car ownership rate, it is observed on the chart in Figure 3.20 that modal share of private cars in all trips have at least slightly decrased from 2007 to 2018. Moreover, the share of public transportation was increased from %9 in 2013 to 16% in 2018, which could be as a result of changing development strategies.

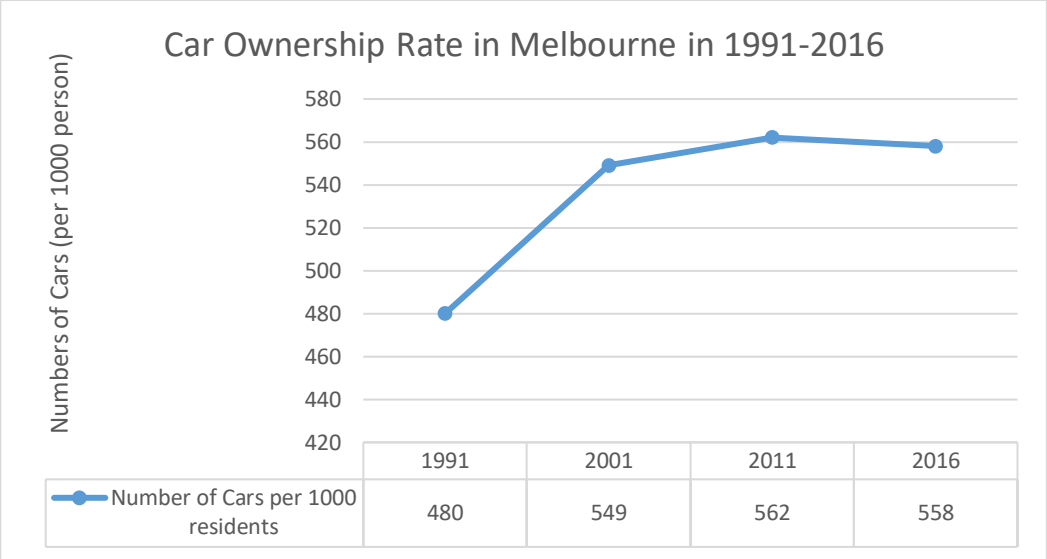


Figure 3.19 Change in Car Ownership Rate in Melbourne

Source: Produced by the author based on data sourced Australian Breu of Statistics

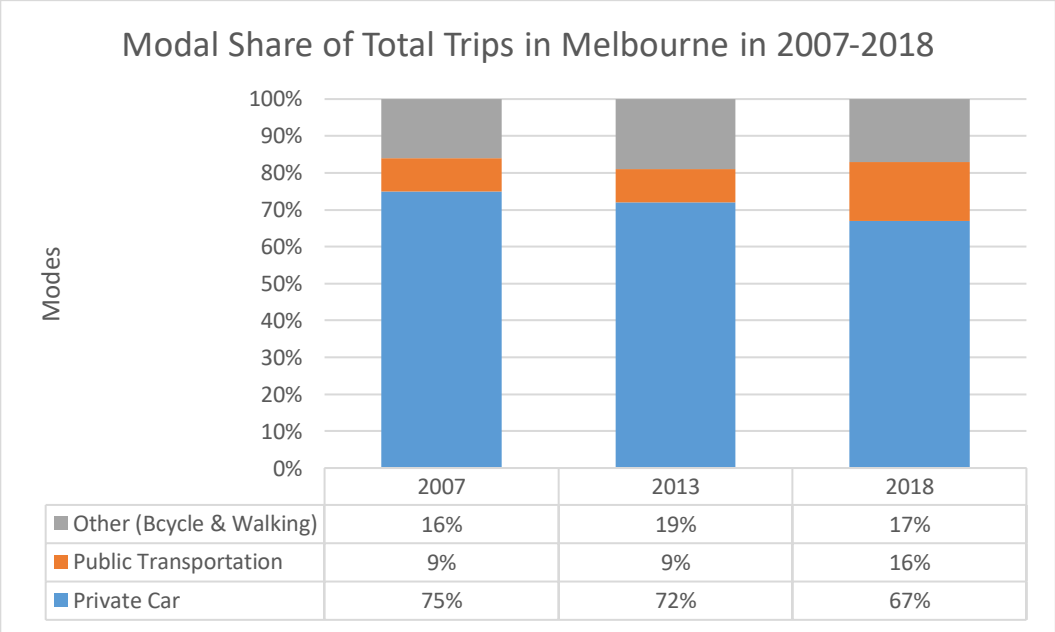


Figure 3.20 Change in Modal Share of Total Trips in Melbourne

Source: Produced by the author based on data sourced Australian Breu of Statistics

In summary, it is a metropolitan area known as the city of suburbans whose settlement area spanned over more than 40 kilometers as a result of the population jumps and economic prosperity it has experienced since the late 1800s. The city of Melbourne is a compact city appreciated with one of the best-developed inner city public transit network although facilities provided by metropolitan area wide public transportation seem to be unable to cope with use of private car for daily journeys. It is supposed that strategies for intermodal integration would have in practice so that public transportation could service the urban areas with very low population density at 40 km away from the city. Melbourne metropolitan area is chosen as a case to be investigated in the scope of this study because it was found distincitive to determine existing conditions of intermodal integration in public transportation and the extent to which it could prevent car dependency in the settlement with such conditions.

3.2.4 Transport Policies and Related Research Results

Melbourne as the Metropolitan area has been associated with a high-profile public transportation sytem in its history thanks to its extensive suburban rail network and well-developed tram operation in the city. Nevertheless, the market share of private car has increased enourmously after 1950s and cause public transport share to capture only 7% of the daily trips within the metropolitan area between 1980-1990s. This was the period in which most of the investments are appealed on improving the road capacity in already existing urban areas as well as the new development zones. Having confronted with the economic and social problems resulted by over-dependency on private car, remarkable efforts has been made to recover public transportation network as a sustainable alternative since 2001. The strategic goal to achieve a public transportation share of 15% by 2020 revealed by Scheurer (2009, p.8) is also an evidence for the attemps for resurgence. The official planning offices had pointed out in 1953 report that effective coordination of all types of public transportation such as trains, trams and busses have to be enabled so that it could perform as a network for mobility (MMBW, 1971, p.72).

The govenrment of Victoria was the operating body for rail and tram services in the region for many decades while the bus services were mostly in possession of private firms contracted by the government. After the rapid fall in whole public transportation patronage and revenue followed by reduced services and rised fares in 1950s, government subsidies are provided both for public and private operators to keep trains, trams and busses running (Mees, 2005).

The liberal government newly elected in 1993 launched a Public Transport Reform Program for the aim of improving the efficiency of Public Transportation Corporation of that times. Then the corporation was divided into seperate bodies, which are V/Line for regional rural rail and feeder bus services, Bayside and Hillside trains for Melbourne Metropolitan rail network, and Swanston and Yarra trams for operating the tram network in 1998 (Mees, 2005). This was the first step of fully privatization of rail and tram services in Melbourne in 1999, when the bus services had already been privatized. The contracted companies commited for the recovered services, rised patronage, stability in fares and diminished government subsidies. So the government bodies expected that the patronage would dramaticaly jump after privatization.

The transport policies changing based on dramatic degradation of public transportation network in Melbourne and institutional initiatives for revitalization of it have been the subject of several researches. Mees (2005) after searching the privatization of rail and tram services and its results put forward that the first change that passengers noticed after privatization was rapid diminishing of system integration which was enabled to an extent in PTC period, although it had guaranted improving the service level. It is because the each of the several independent operators redesigned vehicles and timetables according to its own profit and regard other operators as competitors. For instance, timetables of Hillside operated trains have not revealed to stations on central business district (CBD) loop that are operated by Bayside Trains –another company, which resulted in uncoordinated train schedules even in the central stations.

Dennis Cliche, who was the CEO of Yarra Trams, stated that because a mechanism by which different shareholders could get together and redesign public transport service standards so that the intermodal connections are maximised and a real network is formed, each individual operater within the system considers their own operation. He also claims that Metlink -the metropolitan rail service provider- does not perform any attempts in this regard (Lazanas & Stone, 2010).

In summary, the share of public transportation dramatically dropped due to several factors, which was attempted to be recovered by contracting public transportation services in parts to companies. However, the arrangements established through privitization have failed to fulfil the promises despite the clear government policies for improved intermodal connectivity. This is also confirmed by a study of Public Transport Users Association (PTUA) in early 2010 found that just 38% of train arrivals have bus connections at stations, 43% of which require waiting for trains more than 10 minutes (as cited in Lazanas & Stone, 2010, p.6). Another study by Lazanas & Stone (2010) have also revealed that a sample of points at which high demand for interchange between bus and train is expected also shows poor timetable coordination.

Public transportation incentive policies were re-indroduced after 2001. The attempts for ensuring institutional integration for public transport operations were put into practice on the one hand while further strategies for tranport integration had been developed on the other hand. Transport Integration Act 2010 is the most distinctive evidence of these attempts. The objectives defined under the Act includes the aim of improving the efficiency, coordination, and reliability in public transportation (Victoria State Government, 2019). Furthermore, ensuring a transport system facilitating network-wide reliable, coordinated and efficient mobility, integrated and seamless travel regardless of the modes to be used are some of the policies developed under that aim (Victoria State Government, 2019). Besides, the Act proposed a particular body for public transport and defined some of its functions as consructing, maintaining, or assisting other transport bodies, and planning for the public transport system as part of an integrated network (Victoria State Government, 2019).

Public Transport Victoria (PTV) was transformed into a body that was defined by the Act. The role, authority and staff of Public Transport Victoria were assigned to the Department under regulations of the Act. The scope of PTV has been expanding as various institutions gather under the common roof. Finally, PTV –that is responsible for public transportation- and Vicroads came together as the two branches of the Department of Transport in 2019 (Public Transport Victoria, 2019). The new Department provides integrated focus on problems in transportation network. Increasing share of public transport in all trips in the metropolitan Melbourne in the last decade could be considered as an evidence of current strategies and operational attempts to ensure an integrated transport network (Public Transport Victoria, 2019)

3.2.5 Transportation Network Characteristics

The system of public transportation in Melbourne Metropolitan area consists of trains, trams and busses which are fully privatized. The network comprised of three modes offers a range of public transit facilities to enable full accessibility. The main mode connecting parts of the Metropolitan area is the train while trams constitute the skeleton of public transport throughout the central city of Melbourne.

The metropolitan train routes that are radiating from the central loop in the city of Melbourne are presented in the mapbelow. The overall network comprised of these radiants covers a wide area. However, it is known that the leading factor in spreading city along these corridors was the investmenst in road infrastructure and the increase in car ownership.

The most frequent feature of all metro train routes is availability of bus connections at almost all stops –symbolized by the orange triangle- giving a clue that train-bus integration is achieved spatially. Getting closer to the central city, the bus connection is replaced by the train-tram connection which is symbolized by the green square. That is, the metropolitan train network is accessed through the feeder busses in

remote suburban areas where the density is relatively low while the role of busses is replaced by that of an immense tram network in the city center.

The map in Figure 3.21 shows the routes of trains, trams, and busses with headways. Accordingly, there are bus lines presented by darkest blue on the map which have 10 minutes headways –the minimum headway in all lines- but only available at a few particular routes. The lines shown by lighter blue are the SmartBus lines which move with a headway of approximately 15 minutes allowing radiants to be connected each others at certain distances from the center. Then the lines in light blue follows, which are the local buses providing connections from residential areas to train and tram stops and are located frequently in the space. However, these bus lines do not exist in the city center because the bus service is replaced by tram lines as frequent as the bus routes in suburban areas. Furthermore, there are bus lines that serve with headways of 40 mins, 60 mins, and 120 mins in low-density subruban areas along the development radiants. These lines are the feeder lines from residential regions with very low density to metro train stations.

It has been determined that the public transportation system in Melbourne is a spatially comprehensive network consisting of regional train, metropolitan train, regional busses, local busses, and tram that are hierarchically connected and spatially integrated at macro scale. It would be useful to examine operational structure of different transit modes in Melbourne where the public transportation is fully privatized. The public transportation sytem is basically split into four parts in terms of operation. There are V/Line for regional trains, Metro Melbourne for metropolitan trains, Yarra Trams for tram network, and several private bus operators. V/Line is the largest provider of passenger rail and coach services in regional Victoria (V/Line Corporate Site, 2019). Metro Melbourne operates the metropolitan trains by the quality standards guaranted by the contract of Victorian government. It transports 450.000 passengers each day with the aim of providing a seamless transport for individuals to be connected (METRO, 2019). Yarra trams is responsible for daily operation of extensive tram network of Melbourne. There are also many different bus operators in metropolitan Melbourne and regional Victoria. However, all of these

operator companies are contracted by the Public Transport Victoria, the government body responsible for the public transportation services under the Department of Economics, Development, Jobs and Transportation. It is a contractor holding the authority of safety regulation, sustainable funding, network planning, developing the ticketing sytsem, and coordinating the timetables of three modes.

There is no available evidence about the timetabling of trains, trams, and busses on the network maps. However, Mees (2010) claims that radial trips are easy but travelling from suburbs to destinations except the city center is inconvenient because the timetables of trains and other services never integrated and an additional fare is required for each transfer. It is usually confronted in the related research results that integration of modes in terms of timetabling was poor in Melbourne metropolitan area. Considering the ticketing system, no matter what form of public transport is used, a Myki card can pay for all of them. It is a reusable travel card to pay for travel on trains, trams and buses in Melbourne and regional Victorian centres. Users of Myki either top it money up or pay for a pass before travelling (Public Transit Victoria, 2019b).

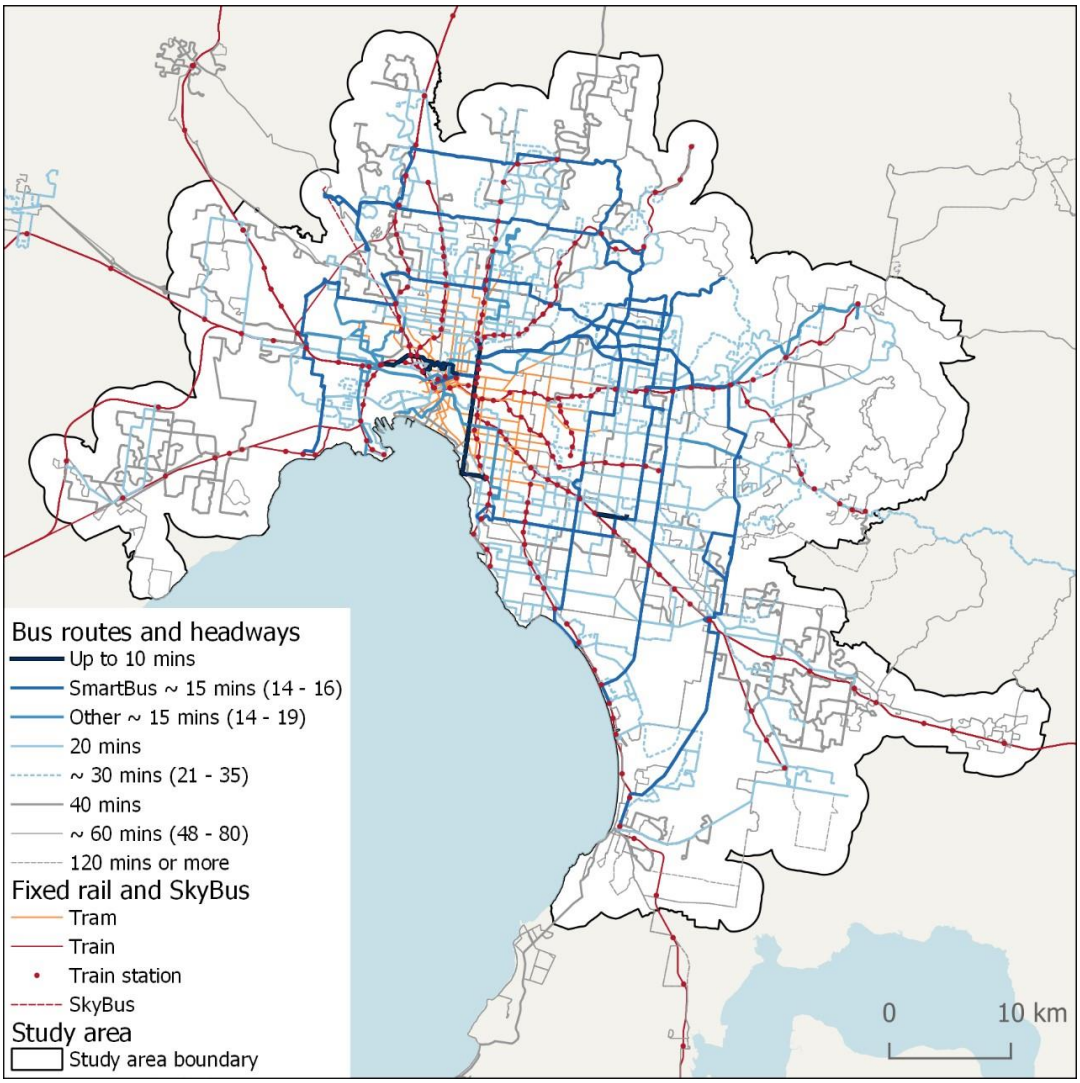


Figure 3.21 Map of Transportation Network in Melbourne

Source: Public Transport Victoria, 2015

3.2.6 Identification of Case Line and Stations

The rail route that is decided to be explored in Melbourne is the Metro train line along the southeastern radiant to Dandenong and Pakenham stations highlighted in map1 below. There are two main factors for choosing this line as a case. The most crucial factor is –similar to Zürich case- the population density along the line. Not only the southeast radiant, but also the north and the northwest radiants have

relatively higher population density –approximately 40-55 person per hectare which is the nearest to that of Ankara- in comparison to other parts of the Metropolitan area. Thus, the second factor was deterministic in deciding among these three radiants, which is the presence of an alternative tram lines. The lines along north and northwest directions have adjacent tram lines serving parallel to the train line, which could depreciate the role of rail service and mislead the data to be analyzed to comprehend the integration facilities between rail and feeder busses. Therefore, the southeast line is the most appropriate alternative for the scope of this study.

The metro train line from the Melbourne city to south-east direction passes through several suburbs that are largely populated. The total population comprised of these settlements is allocated by very low density (5-25 person per hectaree) at the southeast end of the line section, low density (25-50 person per hectaree) at the mid section, and medium-high density (55-150 person per hectaree) at the section composed of inner area as seen in Figure 3.16. These characteristics are supposed to be helpful in accurately comparing the real practices of integration in public transport in different cities.

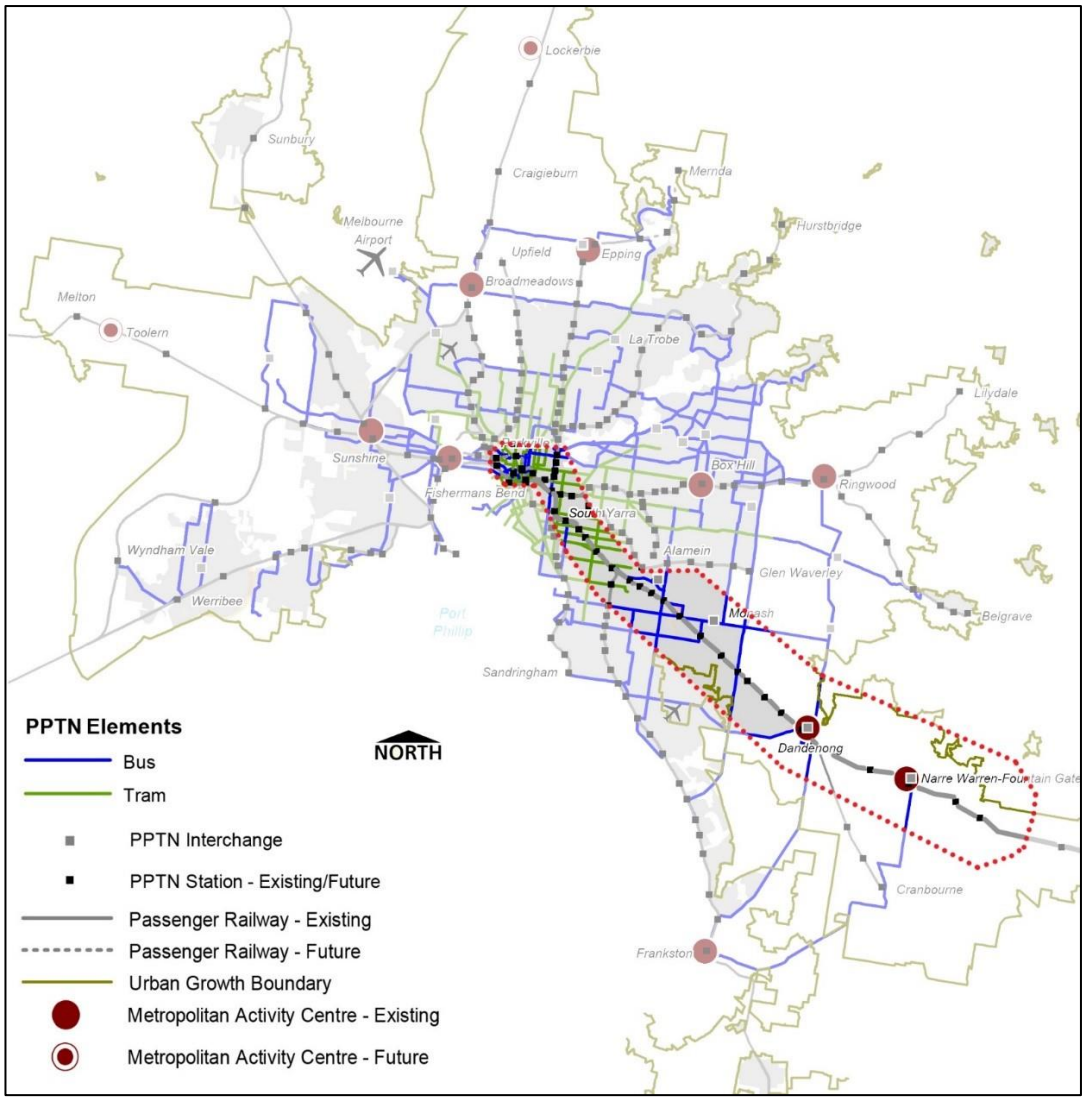


Figure 3.22 Map of Metro Train Route in Melbourne

Source: Public Transport Victoria, 2015

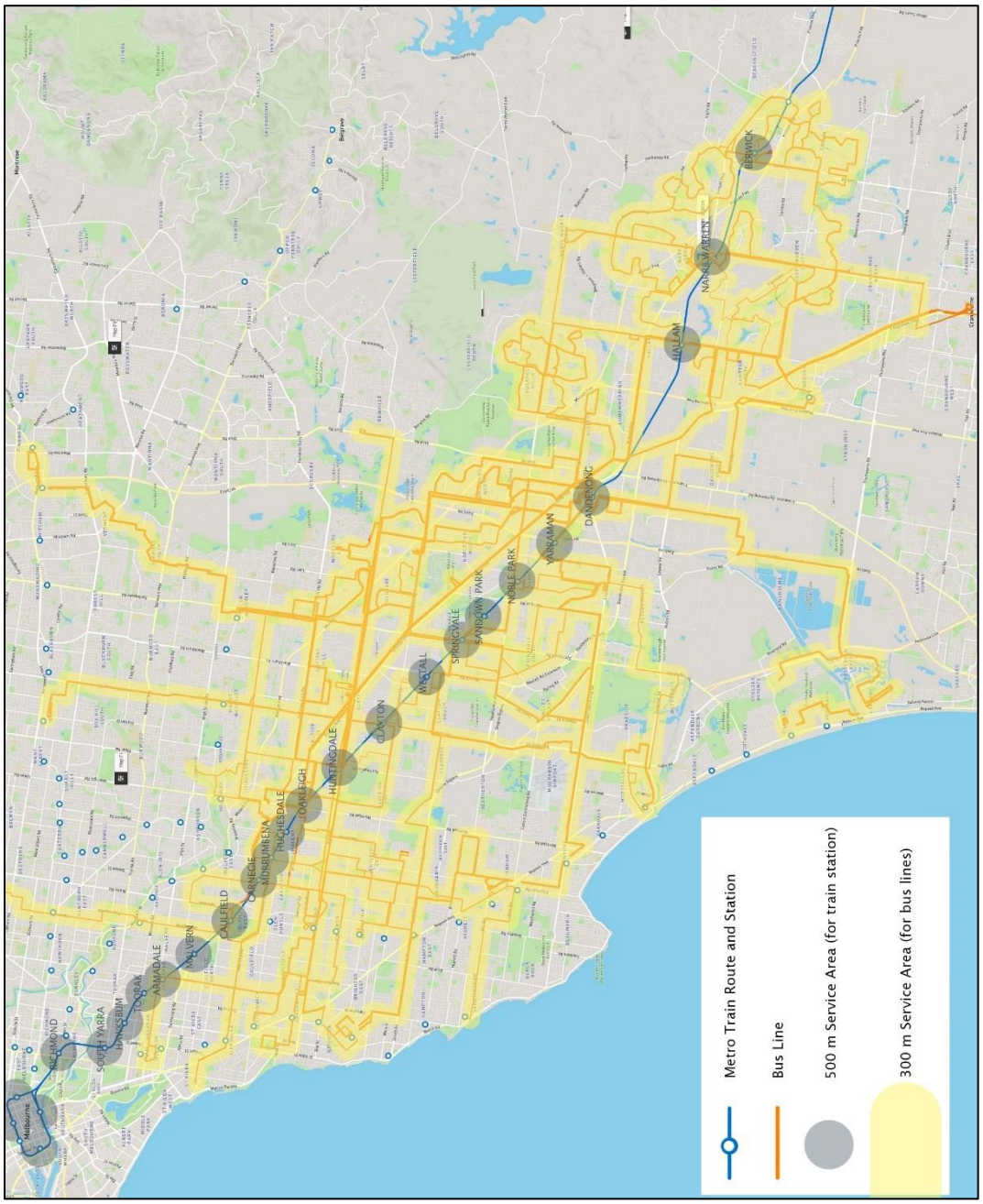


Figure 3.23 Service Area of Metro Train Route and Feeder Bus Lines in Melbourne

Source: Produced by the author based on data sourced Public Transport Victoria, 2019c

The network of rail line and busses connected are illustrated in the maps in Figure 3.22 and Figure 3.23 above. Additionally, there is a representation of 500 meters radius service area of rail stations and 300 meters radius service area of bus lines. These stand for the areas with direct access to the busses at walking distance, and direct or indirect access to the rail stations. The total length of the line segment from Melbourne City center to Narre Warren is approximately 40 km along which 20 stations are allocated. Accordingly, the average distance between the station on the line is 2 km. Considering the stations on the line and 500 meters radius service area around them, it is observed that very litle area is covered. That is, quite little amount of population along the corridor has a direct access to the rail service but the coverage is considerably expanded when connected with the feeder bus lines. Although a very large portion of the population around the line are connected to the service by feeder buses, there are also many uncovered areas between the service areas with a radius of 300 meters. This is mostly because the radius of the service area is assumed to be 300 meters as it is in Zürich, so that the cases explored could be comparable. Yet, these areas are mostly covered when the service area of bus lines are extended to 600 or 800 meters –the highest walking distance- radius, which would be acceptable in approximetly 400 km^2 service area.

The farthest location connected to the rail line by bus service is aproximately at 7,6 km distance to the station, which is accessed in 19 minutes. Moreover, the average distance to the station is 2,7 km and average access time is 10,6 minutes considering the randomly selected addresses and travel directions proposed by online travel planner available on official website of PTV (Public Transit Victoria, 2019c). Accordingly, the average access time is regarded as quite high in relative to the distances travelled to reach the rail station. It is because the busses rambles within the neighborhoods instead of directly connecting an origin settlement to a destination rail station, and serve to another stations instead of usually being destinated to the nearest rail station, that is demonstrated on the map. Moreover, there are alternative metro train lines that connect the neighboring suburbs from the north and south of the line to the city center, to which the many feeder bus services are commonly

utilized. That is, there are many bus lines departing from a station of the rail line to the south and destined to a station of the case line after rambling in the neighborhoods in between the two. Then, they go further to the northern neighborhoods and reach at a station of the rail line to the north. Thus, the travel time as well as the route length increases, the headway decrease, waiting time increases as a result of which the attractivity of travelling by public transportation including a transfer from bus to rail would be diminished.

In summary, the metro train line and feeders bus lines form a densely knitted spatial network. Similar to Zürich, a travel within a zone or between an origin zone to a destination zone is considered as a single transportation activity regardless of a transfer from one mode to another is needed or not. Thus there is no extra payment required for each public transit vehicles taken for a single transportation activity but a single payment through presenting Myki Card at both departing and arrival stations whatever the mode is. Thus it is inferred that ticketing integration from the perspective of passengers is also provided by enabling the zone-based fare system.

Further criteria for multimodal transport integration that are underlined in the literature part is to be examined through analysis of case stations on the line. The Clayton station and the Narre Warren station are selected as the two case for station-specific examination depending on three main criteria. The first is the availability of bus to train integration and unavailability of tram to train integration so that it does not depress the role of feeder busses. The second is that there is not a near station which is on another line connected to the center. Thirdly, it is decided to explore a station in a suburb with a very low population density and another station in a suburb with relatively higher population density. Hence, one of the stations –Narre Warren- is at the southeast end of the line segment, where the population density is about 5-25 person per hectare while the other –Clayton- is at the mid section where the population density is about 25-50 person per hectare as seen Figure 3.16. These stations are selected as the cases where the integration facilities can be best observed and compared.

3.2.6.1 Clayton Station and Bus Lines

Clayton is a suburb in Melbourne with the population of 19.400 in 2016 according to the official statistics revealed by Australian Breu of Statistics. It is located at South-east of Melbourne city center with approximately 18 km distance. The metro rail line segment that is examined as a case has a station at Clayton which is situated at commercial center of the suburb.

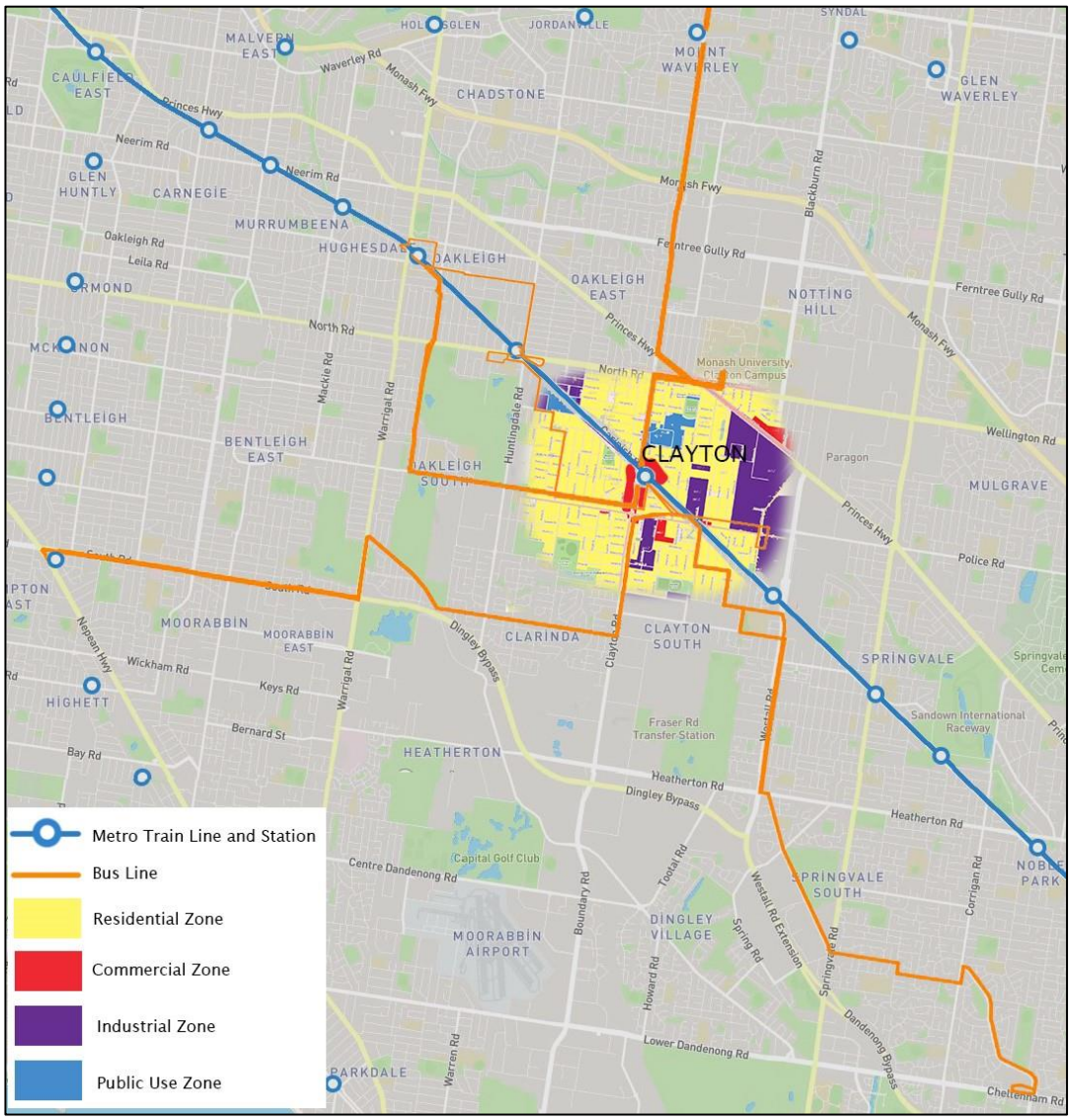


Figure 3.24 Map of Clayton Station and Feeder Bus Lines

Source: Produced by the author based on data sourced Public Transport Victoria, 2019c

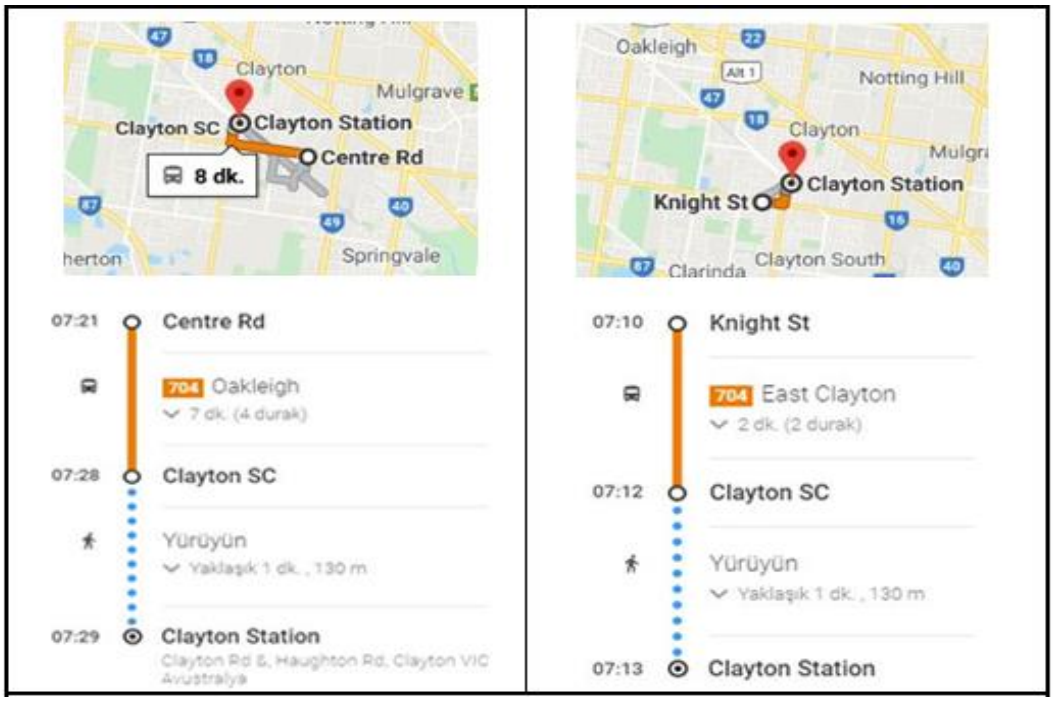


Figure 3.25 Travel Options from BL704 Stops at Min-Med Distances to Clayton Station

Source: Public Transport Victoria, 2019c

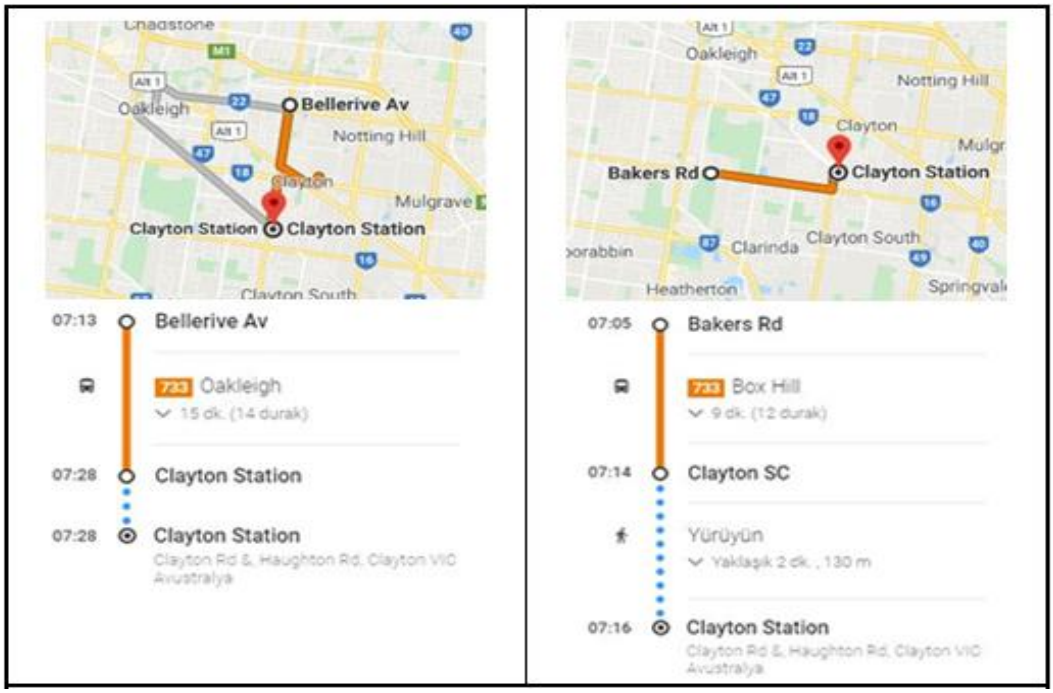


Figure 3.26 Travel Options from BL733 Stops at Min-Med Distances to Clayton Station

Source: Public Transport Victoria, 2019c

Accessing from the furthest bus stop on the bus line 704 to the Clayton station necessitates a 7-minutes in-bus travel. The time cost of bus travel is however equals to 2 minutes when travelling fom the medium stop on the bus line. It is needed to walk approximately 130 m –corresponding to 1-minute time cost- to reach the station.

Another bus line linked to the Clayton station as a feeder –bus line 733- has its last stops at a longer distance, accessing to the station from which includes a 15 minutes in-bus travel. The stop on the same line but at a medium-length distance to the station requires 9 minutes travel by bus to reach the stop, 2-minutes of walking to reach the station from where is required.

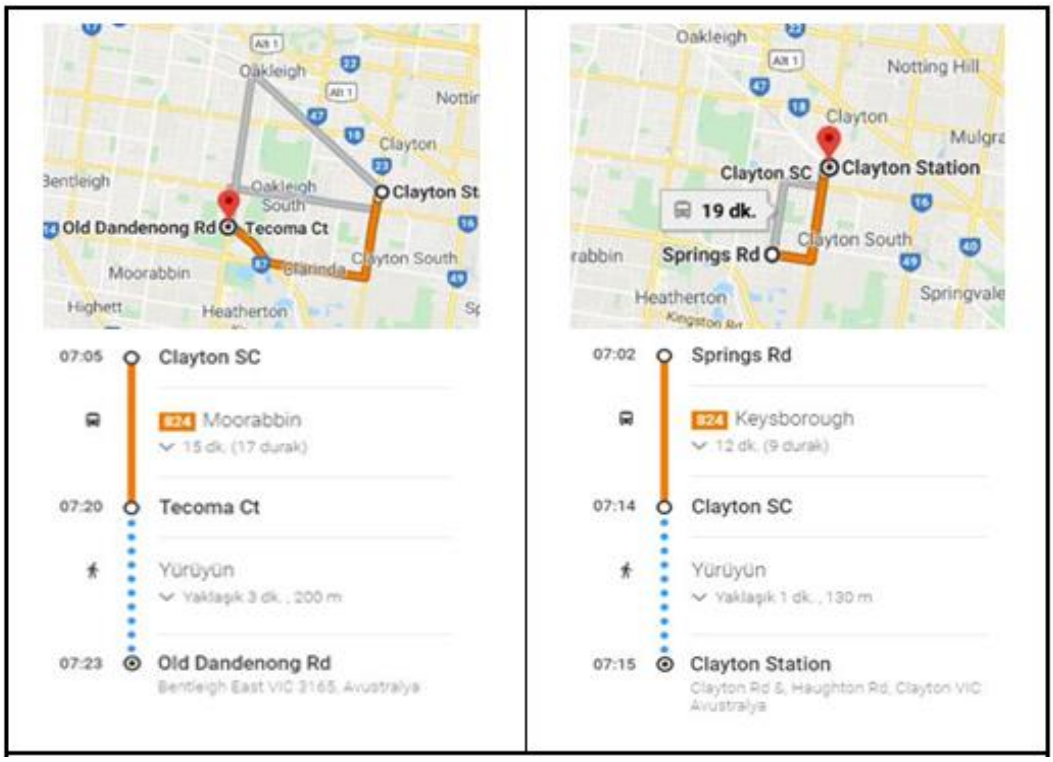


Figure 3.27 Travel Options from BL824 Stops at Min-Med Distances to Clayton Station

Source: Public Transport Victoria, 2019c

The bus line 733- has its last stops at a longer distance, accessing to the station from which includes a 15 minutes in-bus travel. The stop on the same line but at a medium-length distance to the station requires 9 minutes travel by bus to reach the stop, 2-minutes of walking to reach the station from where is required.

3.2.6.2 Narre Warren Station and Bus Lines

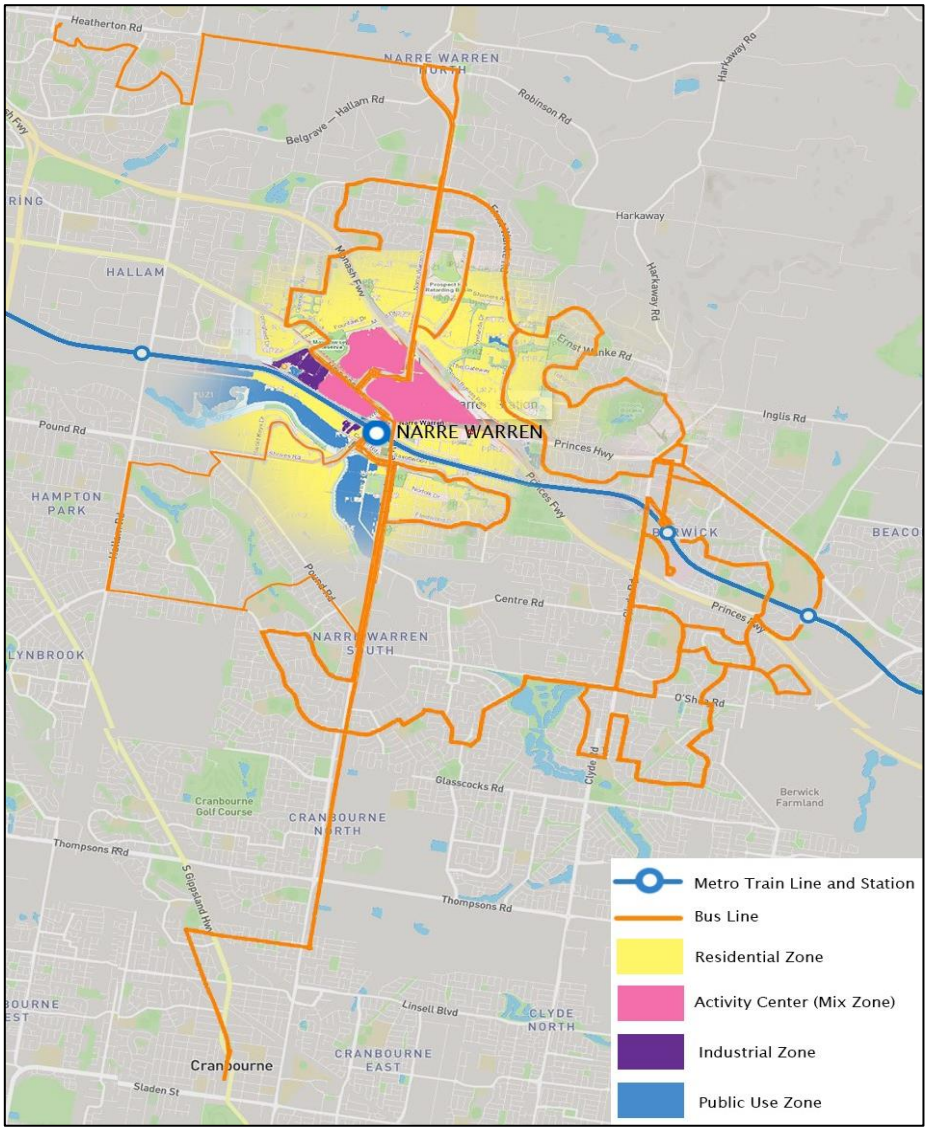


Figure 3.28 Map of Narre Warren Station and Feeder Bus Lines

Source: Produced by the author based on data sourced Public Transport Victoria, 2019c

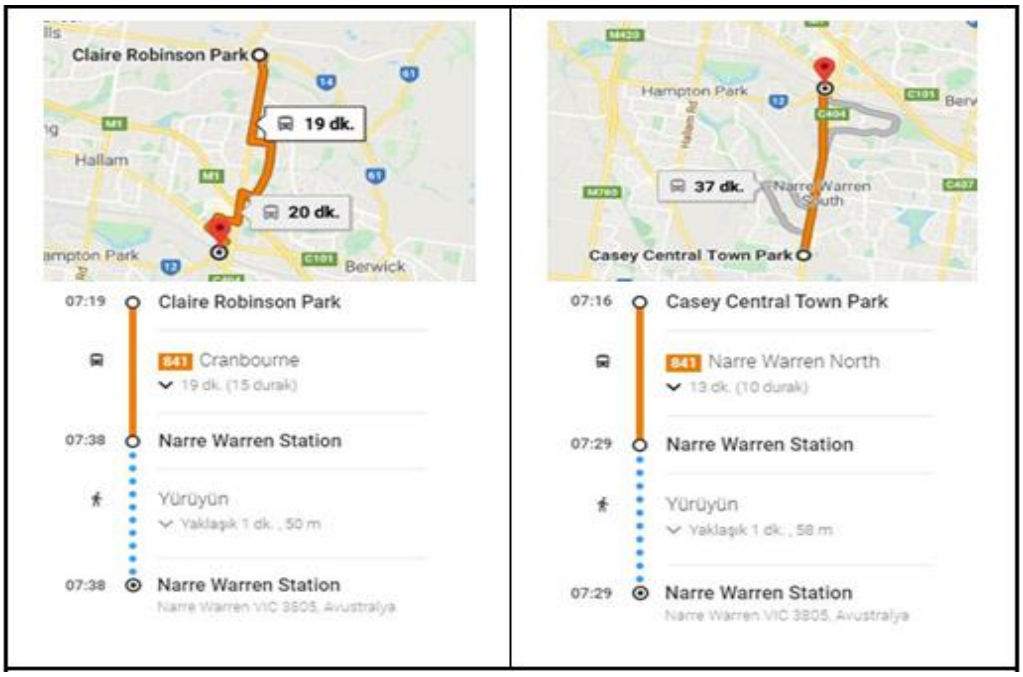


Figure 3.29 Travel Options from BL841 Stops at Max-Med Distances to Narre Station

Source: Public Transport Victoria, 2019c

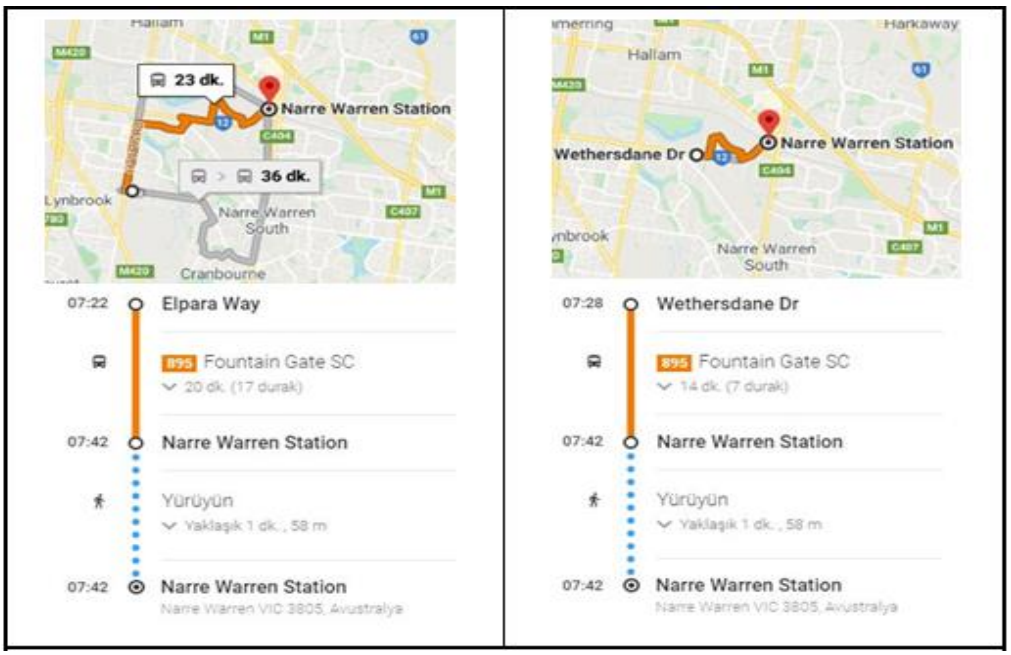


Figure 3.30 Travel Options from BL895 Stops at Max-Med Distances to Narre Station

Source: Public Transport Victoria, 2019c

3.3 Conclusion

Investigation of integration characteristics of different transit system and their possible effects on public transit use in Canton of Zürich and Melbourne Metropolitan area have provided an essential background knowledge based on which the case of Ankara could be evaluated. Basically, the population density have rise as a result of population growth in the both cases. Not interestingly, it is expected that the demand for urban transportation would increase as the number of people using urban activities in a given area increases. So the extend and quality of multimodal integration in transit system, how the private car ownership rate and public transit use have changed under these conditions are remarkable findings both for the scope of current research and for others.

Regarding the travel choices in the both cases, the car ownership rates have been stable including slight falls and share of public transit use in all trips have rised in the last decade. Zürich has experienced a stability in car ownership rate between 2012-2017 after a rise from 362 in 1999 to 484 in 2010, and a rise in the share of public transit use in all trips from 37%in 2010 to 46% in 2017. Similarly, the car ownership rate in Melbourne has slightly fall from 562 in 2011. The share of public transit use on the other hand has increased from 9% in 2013 to 16% in 2018 in parallel to stability in car ownership rate. Thus, the inference that alternative choices would be particularly promoted in order to cutting the increase of private car use is confirmed by data showing the change trend in modal share of total trips. Moreover, the stability in the car ownership rates -which had experienced an increasing trend- although the population growth indicates particular efforts to promote public transportation facilities as an alternative to the use of private car in the case cities.

Transport policies implemented in Zürich and some related research results also confirm that public transit use in Zürich is higher than other central cities in Switzerland and Europe. The main factor for this success is mostly regarded as the ZVV –the cantonal official body for transit operation- functions as an integrated network. More specificaly, transit system in Zürich is mostly associated with high

frequencies and reliable services in all corridors with multi-modal fares and easing transfers between routes. It is commonly emphasised that economical densities of patronage in Zürich allow trams to cross-subsidize busses as well as keeping the city center free from congestion of busses. In Melbourne on the other hand, share of public transportation has dramatically fall due to several factors which was attempted to be recovered by contracting public transportation services to companies. However it has failed to fulfil the promises for improved intermodal connectivity. The studies commonly revealed that the schedule integration of different modes was poor even in the major transfer terminals. But the policies for ensuring a transport system facilitating network-wide reliable, coordinated and efficient mobility, integrated and seamless travel regardless of the modes to be used are developed under that aim of recovering transit system after 2001. Increasing share of public transport in all trips in the metropolitan Melbourne in the last decade could be considered as an evidence of current strategies and operational attempts to ensure an integrated transport network.

The basic measures of identity, characteristics of the sample transit corridor, and characteristics of feeder bus services in Zürich and Melbourne are summarised in Table 3.1. The knowledge obtained from the summary table includes the integration policies and their experienced results in two different city in different parts of the world which have quite different population densities but almost the same rate of car ownerhip at a quite high level. Zürich, where the population density (906 per/km2) and share of public transit use (46%) is at a much more higher level despite the 495‰ of car ownership rate, has successed to stop the rising car ownership and to increase the share of public transit use thanks to high frequencies and reliable services with easing transfers between routes. The key issue in its success in encouraging public transit use despite the high level of car ownership and economic wealth is commonly ascribed as the economical densities of patronage allowing trams to cross-subsidize busses. So, the average maximum route distances of bus lines feeding the urban rail line at Küsnacht and Meilen stations are 5,5 km and 4km which are exactly the same as the drive distance, which indicates that the feeder bus lines are directly connected

to the rail stations without rambling in neighborhoods to maximize the passenger number and profit obtained. Similarly, the in-bus travel time to reach from the farthest stop to the rail station is 13,5 minutes at most. Considering the case line is a sub-urban rail line in Zürich, policy of scheduled (pulse) integration in which both the busses and the trains serve with a 30 minutes intervals. It is also known that waiting time is minimized in such a scheduled integration by enabling highly reliable information system for departure and arrival times of the vehicles. Regarding the case of Melbourne, where population density (495 per/km2) and share of public transit use (16%) is at a much more lower level with a really high rate of car ownership (558 ‰) has also succeded to stop the rising car ownership and to slightly increase the share of public transit use in the last decade despite its unsuccesfull policies of conracting the transit services to individual companies. The initial attempts of integrated and seamless travel regardless of the modes to be used are strong enough to change the trend of ever-increasing rate of car ownership and share of automobile use in urban trips. Although the maximum route distances of the sample feeder bus lines are quite short similar to the case in Zürich, their ratio to drive distances of the same routes are 1,2 which means the busses have still operates with a profit maximization concern. In contrast to Zürich, random (brute-force) type of schedule integration is implemented in Melbourne, in which the service frequencies of trains and feeder busses are independently planned as 9 minutes and 34 minutes in sequence. The concerns of maximizing the individual profits of each modes are still clear considering 34 minutes average interval of feeder bus services within a very low population denisty (5-50 per/km2) along the transit corridor, where the trains runs with a 9 mminutes of interval. This could be regarded as the most obvious evidence of Melbourne has just turned its failure in enabling intermodal connectivity to a success story.

The knowledge obtained from investigating the world cases is supposed to provide a basis for understanding and assessing the performance of an integrated multi-modal transit system in providing accessibility to urban activity locations in Ankara. As a pre-discussion, the contributions of exploring these two cases to improving the

integration facilities in Ankara could be driven by the fact that the share of public transit use in Ankara has been decreasing and car ownership rate has been increasing from 2000 in Ankara on the contrary to stability and slight falls in car ownership rate and rise in public transit share in the last decade in the both cases. Besides, the car ownership rate and share of private car use in urban trips in Ankara are lower than the both cases. That is, the two basic drawbacks in encouraging public transit use are weaker in Ankara compared to Zürich and Melbourne. Consequently, it is not impossible to alter the transit providing policies from prioritizing the short-term profits obtained by individual modes into taking the advantage of overall profit of improving the integration between the modes in Ankara.

Table 3.1 Comparison of Integration Measures in Zürich and Melbourne

		ZURICH	MELBOURNE
IDENTITY	SIZE	1729 km²	9900 km²
	POPULATION	1.5 million (2017)	4.9 million (2018)
	DENSITY	906 per/km²	495 per/km²
	CAR OWNERSHIP RATE	495 ‰	558 ‰
	MODAL SPLIT	46 % PT (2017) 40% Car (2017)	16 % PT (2018) 67 % Car (2018)
CHARACTERISTICS OF TRANSIT CORRIDOR	POPULATION DENSITY SERVED BY THE CASE LINE	50-100 per/ha	5-50 per/ha
	LENGHT OF THE METRO LINE	17 km	40 km
	AVR. DISTANCE BTW. THE STATIONS	2 km	2 km
	INTERVAL OF TRAINS	30	9
	INTERVAL OF BUS	30	34
	TRANSFER TYPE	Scheduled (pulse) Integration	Random (brute-force) Integration

CHARACTERISTICS OF FEEDER BUS SERVICE	BUS LINES CONNECTED TO KÜSNACHT STATION			BUS LINES CONNECTED TO MEILEN STATION				BUS LINES CONNECTED TO CLAYTON STATION				BUS LINES CONNECTED TO NARRE WARREN STATION		
	BL 919	BL 918	VERAGE	BL 922	BL 923	BL 925	VERAGE	BL 733	BL 704	BL 824	VERAGE	BL 895	BL 841	AVERAGE
MAX ROUTE DISTANCE -km	5	6	**5,5**	5	4	3	**4**	5	2	5,5	**4,2**	5,5	7,6	**6,6**
DRIVE DISTANCE -km	5	6	**5,5**	5	4	3	**4**	3	1,6	6	**3,5**	6	5,6	**5,8**
RATIO	1,0	1,0	**1,0**	1,0	1,0	1,0	**1,0**	1,7	1,3	0,9	**1,2**	0,9	1,4	**1,1**
IN-BUS TRAVEL TIME FROM THE FARTHEST STOP -minute	12	15	**13,5**	14	12	11	**12,3**	15	7	15	**12,3**	20	19	**19,5**
IN-BUS TRAVEL TIME FROM THE MID STOP -minute	8	9	**8,5**	8	8	8	**7**	9	2	12	**7,7**	14	13	**13,5**
WALKING TIME -minute	3	3	**3**	2	2	2	**2**	1	2	3	**2**	1	1	**1**
INTERVAL OF BUS -minute	30	30	**30**	30	30	30	**30**	20	40	24	**28**	40	40	**40**
AVERAGE BUS WAITING TIME -minute	15	15	**15**	15	15	15	**15**	10	20	12	**14**	20	20	**20**

CHAPTER 4

CASE STUDY

This chapter consists of the case specific analysis of effects of system facilities of integrated multimodal transit system on accessible geography. The first part of the section deals with determination of accessible geography under the given constraints. In this part, the geography that is accessible from the city center through the overall network consisting the metro line and its feeder bus lines in 30-45-60 minutes travel time constraints are exhibited. In this context, the first and second sub-questions described in the previous part are to be answered. It is also explored how the accessible geography is varied in peak and off-peak hours in weekdays and off-peak hours in Sunday in terms of both the spatial pattern and statistical measures, as put forward by the third sub-question. The second part of the section on the other hand explores the travel time allocation within the parts of travels which forms the accessible geography. Thus, the aspects in which the integrated system of metro line and feeder busses is weak in coping with geography is to be identified. How time cost affects mobility in space and accessible geography along certain routes under a fixed time budget will also be revealed by the time-space paths. So the fourth and the fifth sub-questions are supposed to be answered in this part.

4.1 Methodology

The attributes of the users and the disutilities they are exposed to when travelling on Kızılay-Koru metro line including bus integration as well as the impact of these disutilities on travel behaviours are not identified yet. These are no doubt the key factors in determining the required improvements in system performance and its possible effects on accessibility of the serviced geography. Unfortunately, determination of these factors requires extremely comprehensive data collection –

which is not available yet- and analysing processes that depends upon an engineering perspective and thus becomes alienated to concerns of city planning field.

In this study, the performance of integrated multimodal transit system of Kızılay-Çayyolu metro line and feeder bus lines in providing accessibility from the CBD-Kızılay- to urban parts along the transit corridor are assessed from the city planning perspective. That is, the performance of an integrated multi-modal transit system is ascribed to how it affects the accessibility of parts of the city or the ease of accessing to activity locations in other words. Therefore, the time-geographic approach is adopted for discovering the geography that is accessible from the city center by means of Kızılay-Çayyolumetro line and bus lines integrated to it. The precondition for accessibility in this context is defined through the upper limit of time budget, verified data of which is not available in hand. Thus, the assumed travel time budget within this study is based on the constant travel time theory.

Tanner (1961) was first hypothesised possibility of constant travel time budget, which is followed by the empirical researches by Zlazai (1972) suggesting that average daily travel time is more or less the same in a country on aggregate level. Zahavi (1979) precisely argued that indidivdual daily mean travel time budget (TTB) is constant over space and time and is approximatley one hour (as cited in Van Wee, Rietveld & Meurs, 2006). There are also some others which do not confirm the travel time constancy assumption or at least claiming that it is not as strong as hypothesised (Golob et al 1981, Tanner 1981, Hupkes 1982, Purvis 1994, Levinson and Kumar 1995 as cited in Van Wee, Rietveld & Meurs, 2006). These studies have tried to explain observed variations in travel time expenditures based on some variables such as age, gender, income group, employment status of population group and macroform, density, land-use attributes of area types.

Having appreciated that being acknowledged about the contradictory arguments is usefull as a an insight, the discussion on travel time constancy will not furtherly be elaborated as it does not constitute the core of this study. There will be an assumption

of constant individual travel time budget for Ankara metropolitan area, which is not strictly equals one hour as Zahavi suggests. Yet, the accessible areas will be determined under the assumptions of three alternative value for constant travel time budget of 30-45-90 minutes to ensure flexibility in travel time budget.

In this regard, the pratical methods suggested by time-geography approach will be applied in this study. Unlike integral accessibility measures assuming that accessiblity level of a particular destination is dependent on geographical proximity to a single reference origin –which is considered as the unique value of impedance, time-geographic methods are based on multi-criterion impedance values with respect to individual activity sequence and spatio-temporal constraint (Miller, 2005). Travelling from an origin to a final destination via integrated multi-modal transit network is inevitably split into sections by interruptions for interchanging. Accordingly, each of these sections are treated as parts of individual activity sequence that have two essential components. One is activity locations defined by time and space (control points), and the other is the movement paths connecting temporally adjacent activities as suggested by time-space path method of time-geographic approach (Miller, 2005).The minimum information available at each control point is its location and the time when location was recorded:

$$c_i \equiv c(t_i) = x_i \tag{1}$$

where x_i is a location in space, t_i is an instant in time (Miller, 2005, p.26). The set of control points that determine the path is a finite list of space-time inspections that are ordered by time:

$$C=\{(c_S,\ldots, c_i, c_j,\ldots,c_E) \mid t_S < \ldots < t_i < t_j < \ldots < t_E \} \tag{2}$$

where t_S and t_E are the start and end time for the path, that corresponds to the first and last observed locations in space (Miller, 2005, p.26).

Given the control points with time and space information, the simplest representation of path segments is interpolation between adjacent control points using time as a parameter:

$$S_{ij}(t) = (1-\alpha)\, x_i + \alpha x_j \tag{3}$$

Where:

$$\alpha = (t - t_i) \div (t_j - t_i) \tag{4}$$

The figure below illustrates an example of control points and segments in a space-time path (Miller, 2005, p.26).

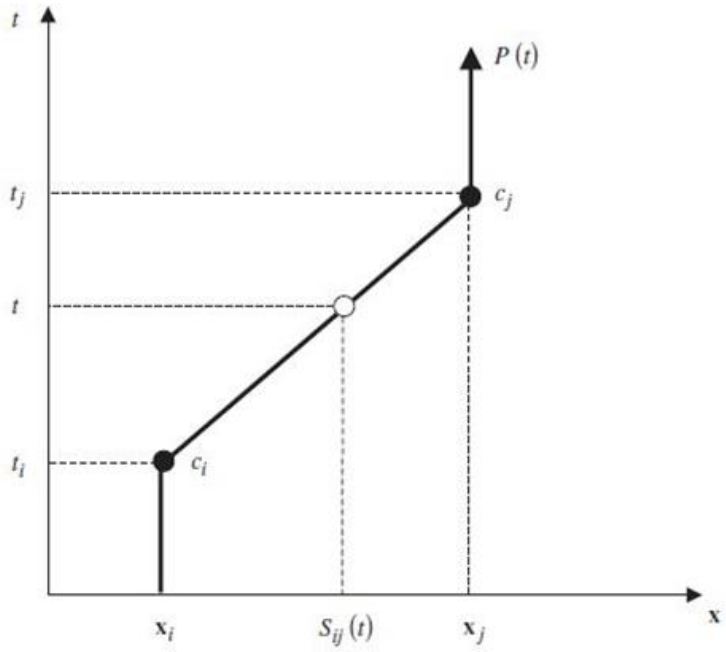


Figure 4.1 An Example of Space Time Path

Source: Miller, 2005, p.27.

Combining the path segments with the control points constructs the following equation for space-time path which is based on time as parameter:

$$P(t) = \begin{cases} c_i, & t \in (t_S, \dots, t_i, t_j, \dots, t_E) \\ S_{ij}(t), & t_i < t < t_j \end{cases} \quad (5)$$

Equation (5) enables to scroll through locations in the space-time path using time as an index (Miller, 2005, p.27).

Given the methodological logic behind the time-geographic approach, the space-time path method will be utilized in exploring and representing the control points of each interuptions of a travel, their durations, and time cost of accessing to an adjacent control point in space. In this way, the time cost of each interruptions and travelling from a control point to the adjacent one will be determined. Then, the overall time cost for travelling from Kızılay –the city center- to each bus stops -the possible final destinations on integrated PT system of Kızılay-Koru metro line and its feeder bus lines- is to be obtained. Time cost of travelling from Kızılay to each stops on feeder bus lines will be assigned as an attribute for each stop. The stops with lower travel time cost than the assumed travel time budget are supposed to generate the geography that is accessible by means of the metro line and integrated bus lines.

The argument of sequence of activities in time geographic appraoch is combined with OD matrix of integral measures, which shows the impedance values between each OD pairs in terms of time or distance cost. The structure of matrix is adjusted such that it presents not only a unique value of impedance for each OD pairs but also impedances caused by each interruptions and each segment of the travel from an origin to the final destination.

Many studies in the literature have been negatively criticised as they do not consider the temporal variability in accessiblity levels, the underlying assumption of which is that distance metric is time invariant (Kaza, 2015). However, the time taken when travelling from an origin to a particular destination varies significantly depending on time of the day or day of the week, mostly as a result of intermittent schedules and waiting times. In this study, time-geographic analysis of accessibility will be conducted for peak and off-peak hours in a weekday and in Sunday in order to assess the variations in time costs and its impacts on distribution of accessible areas.

Essentially, this study follows a methodology combining the space-time path and adjusted impedance matrix within time-geographic appraoch for discovering the geography that is accessible from the CBD under the assumption of constant travel time budget. The temporal variability in geographic distribution of accessible areas is inspected through schedule-based determination of travel time costs for peak and off-peak hours in a weekday and in Sunday. GIS-based tools of data management, spatial analysis and visualisation are employed throughout the study.

4.2 Study Area

Ankara, which is declared as the capital city of Turkey in 1923, has evolved from an approximately 20,000 populated small town where the motorized trips comprises less than 10% of total urban travels into a 5,500,000 populated metropolitan city where the rate of motorized trips is more than 80% of total urban travels. (Demirtaş, 2009; EGO, 2015a; Tunçer, 2001 as cited in Özbilen, 2016). There is no doubt that these changes are resulted by radical changes in both the urban and economic development policies as well as giving rise to further changes on urban macroform.

Having an understanding of the formation of Ankara urban structure and its relation to transportation systems is a requirement for recognition the study area and its convenience to the research field as a context. Thus, a brief history of urban development and changes in urban macroform in relation to major decisions on transportation network is presented in the first part of this section with a particular focus on the development of Çayyolu region as an urban corridor. This part also includes the population change as an aspect of the increasing demand for urban activities and urban transportation to access the activity locations. The second part explores the changes in travel behaviours of citizens in Ankara such as car ownership rate and modal share of urban travels. This is followed by the second part in which the public transportation policies in Ankara and related research results are compiled so that they provide an understanding of the particular changes in travel behaviours based on the policies. Finally, there is a description of the integrated system of

Kızılay-Çayyolu metro line and the feeder bus lines in terms of spatial and operational features of integration and the service area.

4.2.1 Urban Development & Transportation Network in Ankara

Having declared as the capital city of Turkey, Ankara has encountered a series of problems such as squatter housing and uncontrolled urban development as a result of experiencing a rapid growth in population. However, this part summarizes only the main elements of urban urban development through the official development plans because all the scenes creates another research topic outside scope of this study.

The initial attempts for development planning in Ankara have started when the need for offering residential areas to settle the increasing population within the city is realized. The first work planning the urban macroform is prepared with the initial aim of providing the mandatory urban infrastructure to the settlement units in the Histrorical City (Ankara citadel and its surrounding area) in 1924 and in New City (Kızılay-Sıhhiye corridor) in 1925 (ABB, 2006, p.57). Namely the Lörcher plan proposed to build the city on boulevards connecting the surrounding area of the station to Ulus square, the Citadel and Dışkapı axises. It also proposed a radical decision of creating a new residential area along a boulevard from the southern part of the old city to the new city area, which refers to the Sıhhiye-Kızılay region. The residential area is planned as comprising maximum two-story houses with gardens serviced by a grid-iron road network. But the radical proposal for the old city that includes large destrcutions are disaproved on the ground that they are inapplicable. The decisions for constructing a new city as an extention of the existing city towards the south which shapes the surrounding are of Kızılay –the heart of the city today- is approved (ABB, 2006, p.57). This leap in the macroform of the settlement area is a remarkable shift considering the urban distances and mobility trends of that period. The proposal of road network of the Lörcher plan has quickly implemented despite the financial limitations (ABB, 2006, p.57). This is the point at which the urban macroform leads development of urban transportation systems in Ankara where the

most of the intra urban trips were made on foot since the size of the settlement area, the scale and diversity of urban actions were limited in that period (ABB, 2006). The fact that a thirty minutes of pedestrian journeys is needed from Ulus to new city required a transition to a vehicle transportation, and started a new era in public transportation provision in Ankara. The residential area along the new city has met the urgent need for housing but the further increase in city population caused development pressure especially towards Çankaya and Keçiören regions after 1927 (ABB, 2006, p.57).

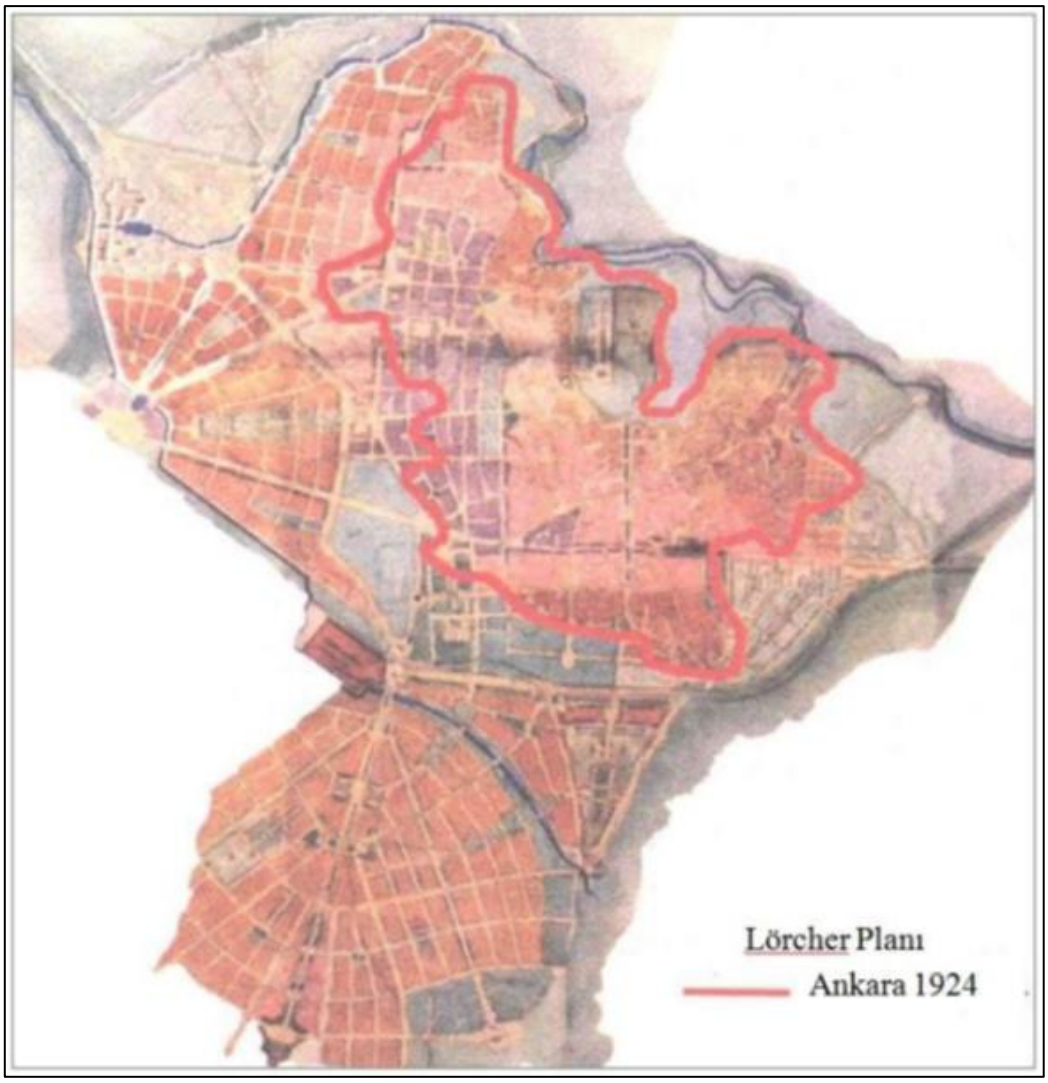


Figure 4.2 Lörcher Plan for Ankara

Source: Ankara Büyükşehir Belediyesi (2006, p.48)

The planning attemps continued in 1928 since the proposals of Lörcher plan for the old city did not approved and those for the new city failed in meeting the demand for housing in a short time period. Jansen plan –the winner of the competition for planning the capital- has accepted to a large extent the development and implementation proposals that Lörcher plan regards for new city. It has planned a residential development on the axis of New City-Kavaklıdere for middle-high income groups whereas the Tandoğan-Bahçelievler and Cebeci –which are defined as the eatern and western ends of the city- are designed as worker districts without much interventions on the old city (ABB, 2006, p.58). Assuming an average of 120-240 per/ha density over a total area of 1500 ha, it predicts an approximately 300,000 population by the year 1978 (ABB, 2006, p.58). This plan, which also considers the formation of a green axis in the east-west direction of the city, aims to develop Ankara as a medium-low density gardencity (ABB, 2006, p.58). Although the certain elements of Jansen plan were implemented in the first years, the plan and the proposed macroform has lost its identity as a result of difficulties encountered in implementation such as land speculations and the city's growing faster than expected (ABB, 2006, p.58). The increasing population growth as a result of emigration from the rural areas after the second World War caused a presure for rapid urbanization in these periods. In adition to unexpected population growth, failure in implementing Jansen Plan resulted in uncontrolled development in Ankara. As a result, the target of 300,000 people in 1978 foreseen by the Janen Plan was reached in the early 1950s and squatter housing emerged as the central problem of the city in the late 1940s (ABB, 2006, p.58). Regarding the decisions on transportation network, the Jansen plan has proposed the construction of a few but high quality roads and aimed to improve the suburban railway. Cebeci station and Atatürk and Gazi Mustafa Kemal Boulevards are the main estates of Jansen's transportation decisions.

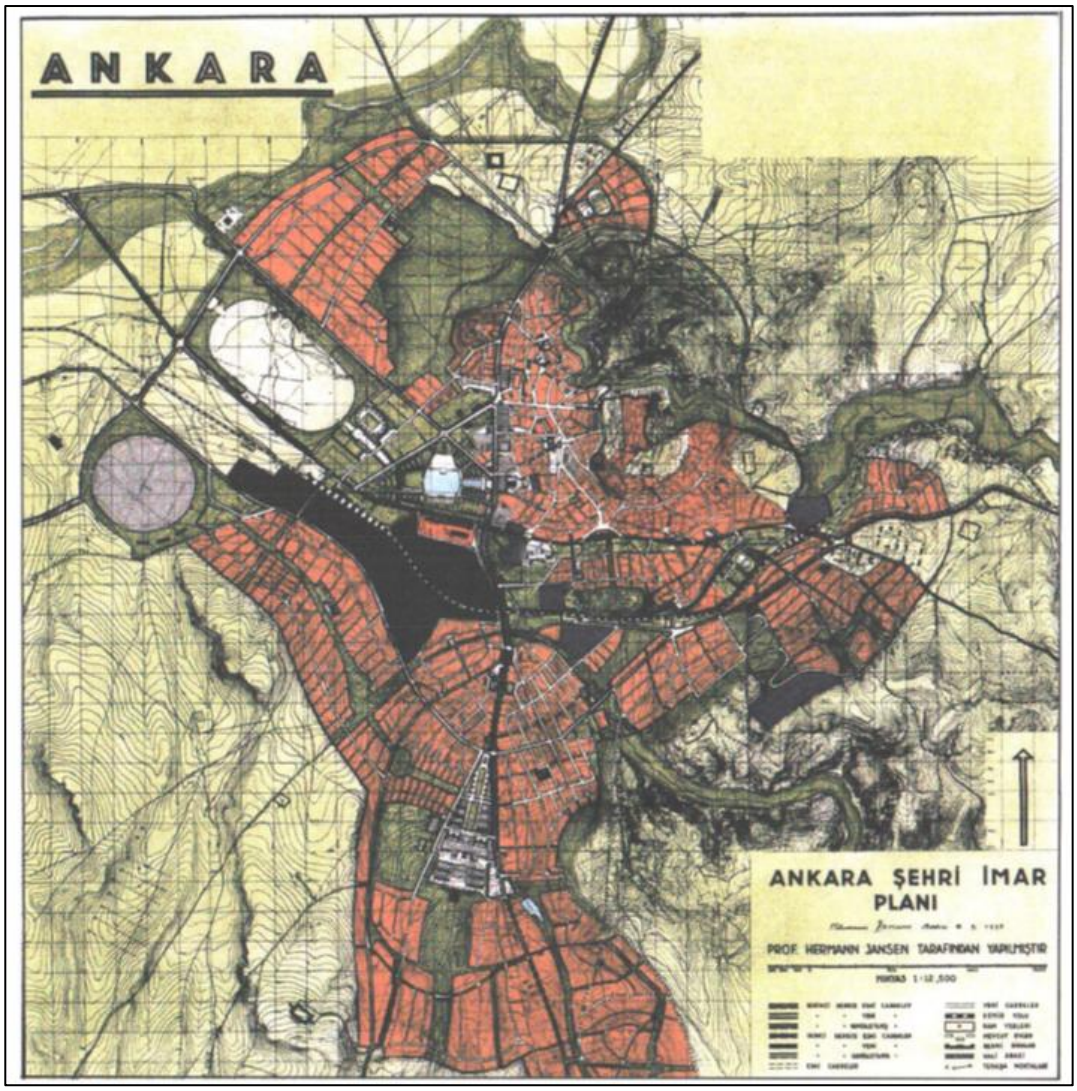


Figure 4.3 Jansen Plan for Ankara

Source: Ankara Büyükşehir Belediyesi (2006, p.49)

The period of late 1950s-1970 is the one in which the pace of urban development and increase in population growth in Ankara are at the peak. The rate of population increase by 89% in the period of 1950-1955 caused the share of the population to that of Turkey rise from 1% in 1940s to 4% in 1970s, which was the driving force of urban development and planning studies (ABB, 2006, p.58). The squatter housing areas emerging along the suburban railway to Kayaş, and on the outskirts of the planned areas in Etlik and Dikmen caused uncontrolled occupation of areas that are not planned for development in the Jansen plan and therefore do not equipped with

the basic infastructure. The recent plan prepared by NihatYücel-Raşit Uybadin and aproved in 1957 attemped to create an integrated macroform by trying to control the spread over the periphery of settlement area at that period (ABB, 2006, p.58). Its main proposal for achieving this purpose is to create a spatial relationship between the working and housing areas by planning residential areas along the suburban railway and requesting an industrial area in Etimesgut (ABB, 2006, p.59). But Condominium Law coming into force in 1965 and approvement of regional floor plans which permit higher number of floors within the already developed areas based on the road widths have blocked implementation of Yücel-Uybadin plans. Increasing the number of floors in buildings in the new city -which was planned as 2-storey garden houses by Lörcher and Jansen plans- to 4 to 10 storeys, this plans have given rise to new problems by increasing the building and population density without changing the road network and other infastructure (ABB, 2006, p.59). The basic intervention of Yücel-Uybadin plan is construction of a ring road –namely the Konya-Samsun road- which is also one of the main arterials in urban area. The population projection of this plan for Ankara in the year 1987 is 750,000 but it was already reached in 1965 (ABB, 2006, p.60). Consequently, the population increase from beginning of the republic until 1970s is always underestimated by the plans which give result to uncontrolled development of urban macroform. Planning a ring road and constructing the first example of crossover intersections on the urban roads indicates that transportation policies prioritizing the development of road network are dominant in this period as it is in the earlier periods. Although EGO services were directed to new development sites, there was no significant improvements in public transportation. The increase in the supply of public transportation could not meet the increasing demand as a result of rapid urbanization (ABB, 2006, p.59).

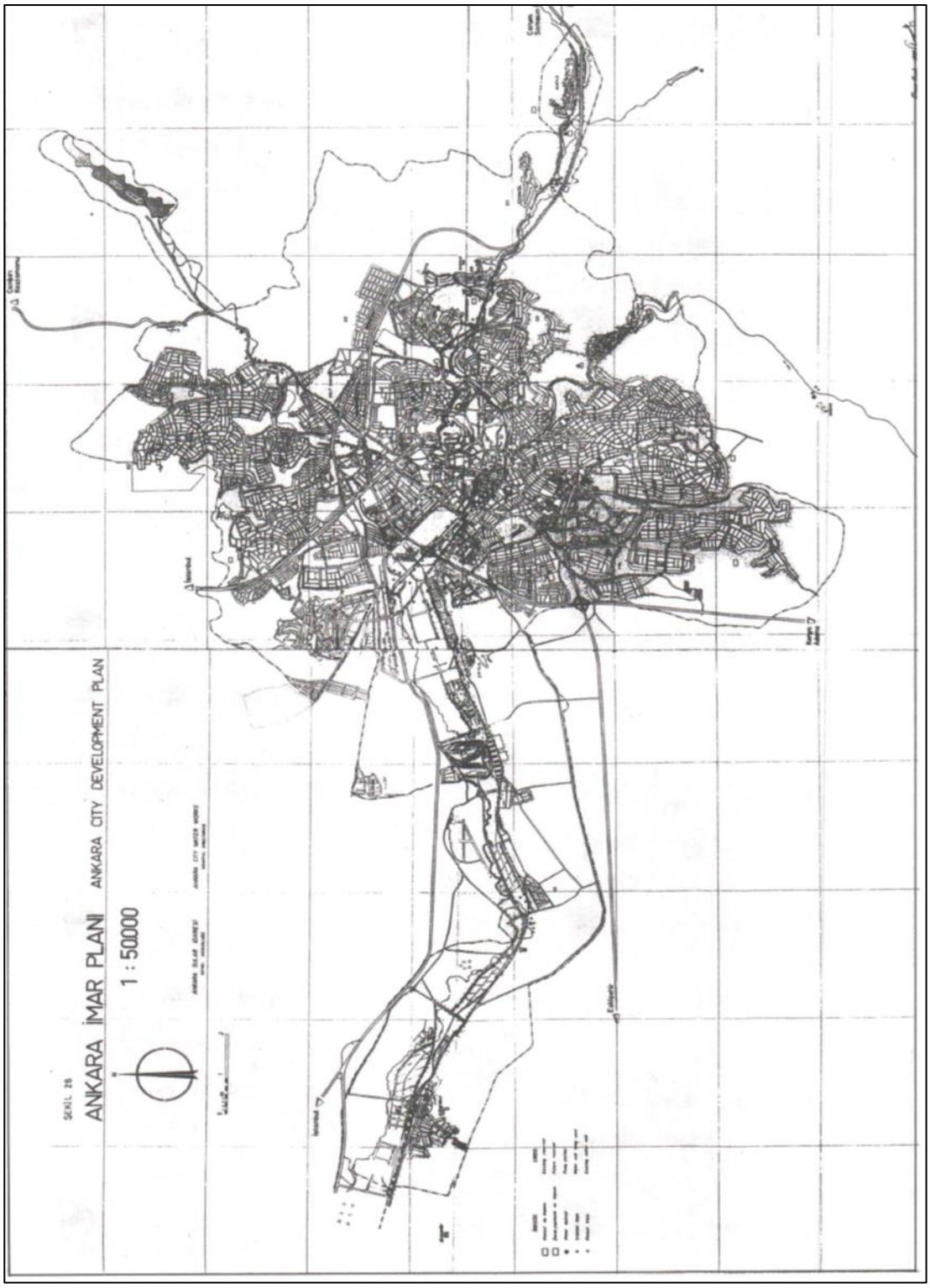


Figure 4.4 Yücel-Uybadin Plan for Ankara

Source: Ankara Büyükşehir Belediyesi (2006, p.50)

The Bureau of Ankara Metropolitan Area Master Plan, which was established in 1969, developed a master plan schema wit a 20-year perpective after comprehensive studies in 1970-1975 and this schema was approved in 1982 as Ankara 1990 Master Plan. The main policy of the Master Plan was to ensure that the urban development that have taken place on north-south direction around the urban core came out of the topographic basin along a main corridor –which is western corridor on İstanbul Road- and thus creating alternative areas both for residential and industrial development (ABB, 2006, p.60). In this context, large residential areas in Batıkent, Eryaman, and Sincan, and industrial region in Sincan are planned and developed as a result of which the city has grown along to the Istanbul road. Meanwhile, the land demand by the cooperatives of civil servants -who could not located in the central city- have reached up to the 15th kilometer along Eskişehir road in 1970-1975 (ABB, 2006, p.60). In addition to low lands suitable for settling in these areas, narrow valleys were opened to the land market and land values increased within a few years (Altaban, 1987; as cited in Aydemir, 2015). Consequently, residential neighborhoods in Çayyolu and Konutkent regions without any central urban uses are started to be formed after 1980 in parallel to site selection of large public uses such as university campus areas and government offices along the Eskişehir road –which is referred as the southwestern corridor in addition to the western corridor of new development. The western corridor in particular was planned for new residential areas and for the decentralization of industrial estates. Predicting the metropolitan population would be in the range of 2,8-3,6 million in 1990, the master plan has changed the urban macroform from an expanding oil stain into urban development radiating from the core along the corridors (ABB, 2006, p.61). However, new problem areas emerged due to the amnesty laws and improvement plans that were issued in this period which also weakened the implementation power of the 1990 Master Plan.

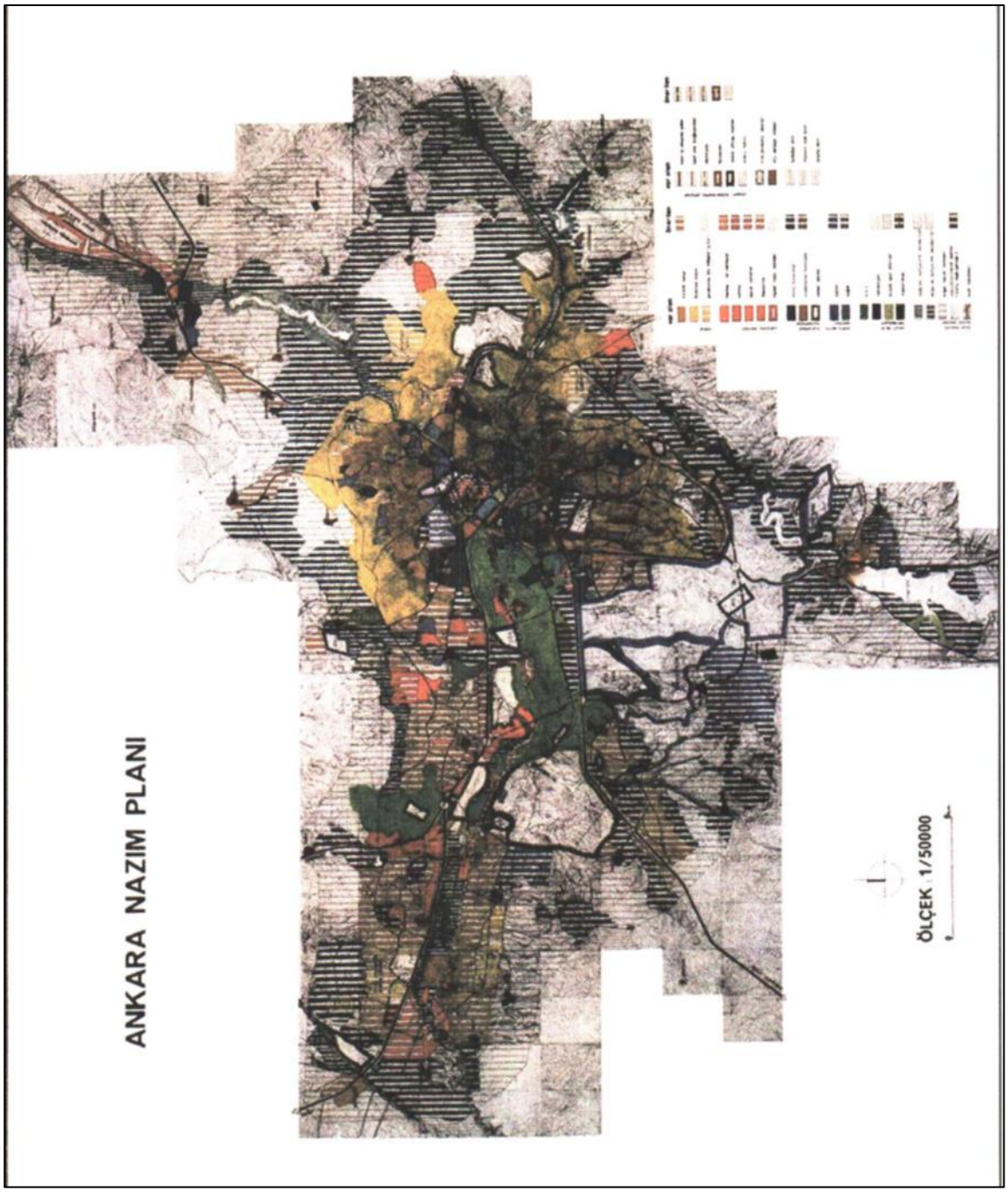


Figure 4.5 Ankara Master Plan for 1990

Source: Ankara Büyükşehir Belediyesi (2006, p.51)

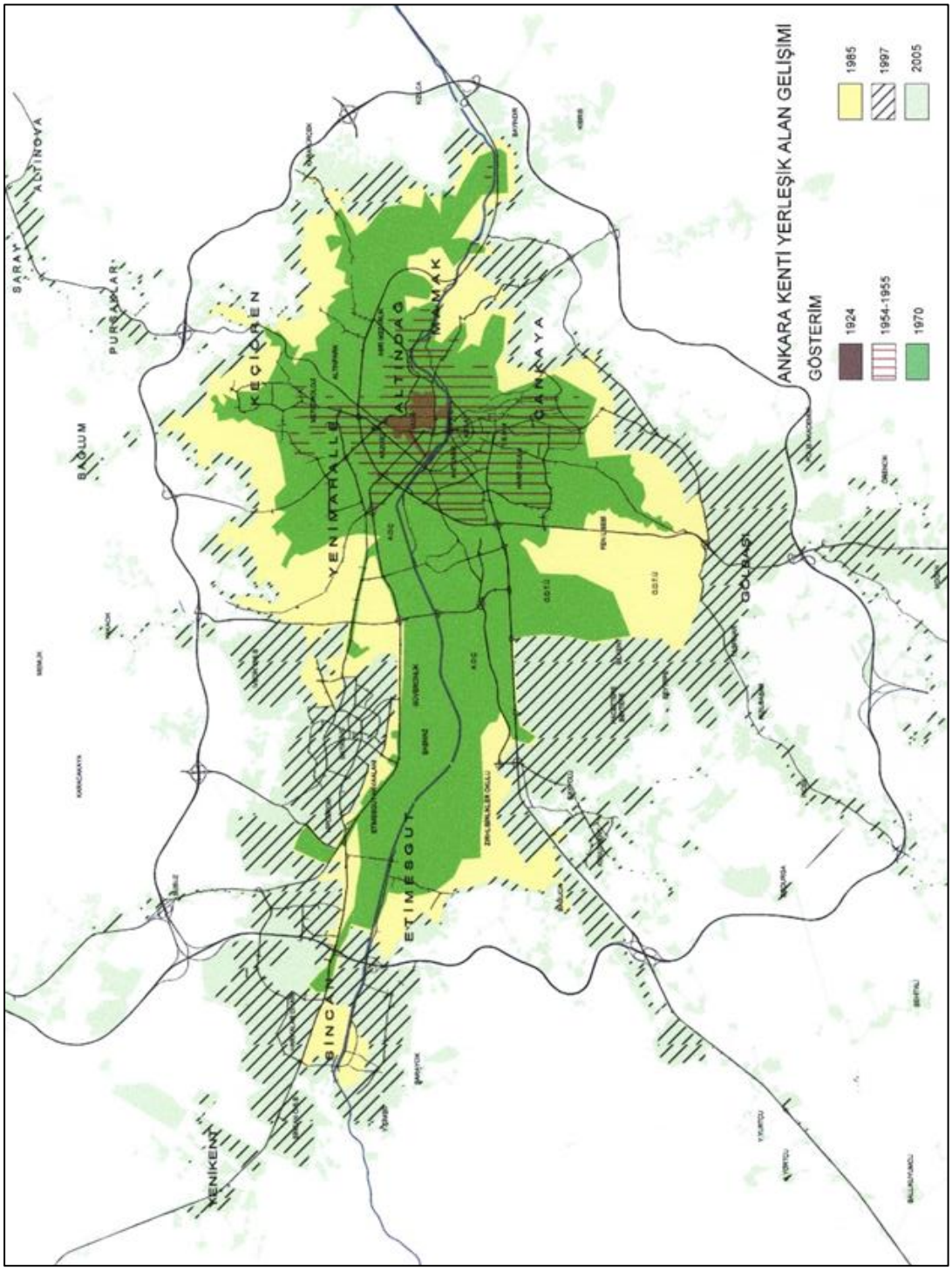


Figure 4.6 Map of Urban Development in Ankara in 1924-2005

Source: Ankara Büyükşehir Belediyesi (2006, p.68)

In the late 1980s, the major problem in Ankara was air pollution in addition to the development problems. Two important planning studies during the period of 1990s were the preparation of Ankara Structural Plan and Ankara Urban Transportation Study. Together with Middle East Technical University's City and Regional Planning Department Working Group, EGO with a working group from Middle East Technical University's City and Regional Planning Department prepared a detailed structural plan for the year 2015. It is initially prepared for providing a basis for the "Transportation Master Plan and Etude for Urban Rail Feasibility", prepared by EGO (ABB, 2006, p.62). Transportation studies started in 1985 in Ankara for the first time in Turkey referred a need for a foresight of urban macroform that could be a basis for transportation plan. So the structural planning studies started for this purpose resulted in a comprehensive spatial development plan which preserves the basic decisions of 1990 Master Plan but proposes further decentralization towards the east, north, northeast and south axises (ABB, 2006, p.62). The radial macroform with ventilation corridors between the development radiants is proposed for the solution of air pollution, transportation problems, and the disorder in relation between working-housing areas. Transportation planning studies that have started in 1985 produced major transportation decisions in parallel to the development pattern determined by the structural plan for the year 2015. Although the structural plan remained as an unoffical basis for the transportation plan as it is not officially approved, the Ankara Transportation Master Plan is approved in 1994. The intention of the plans was to create a corridor development to which some major uses in the CBD would be decentralized, and to support these corridors with high capacity and high quality rail-based public transport (Babalık Sutcliffe, 2013; as cited in Özbilen, 2016). The major public transportation proposals the project and feasibilty studies of which have been under study since 1980s turned into a network wide decisions in coordination with urban macroform development plan. In this respect, a comprehensive urban rail network including metro lines along Batıkent and Çayyolu corridors is planned in phases. The first phase covers the projects that are intended to be constructed until the year 1995. It includes of the Batıkent-Kızılay metro line

as the urban development along this corridor have already started based on the earlier development plans (ABB, 1995, p.86). In addition to this, the light rail system from AŞOT to Dikimevi which was under construction in order to provide an efficient solution for public transportation demand within the urban core and the surrounding area is planned as to be completed in the first phase (ABB, 1995, p.86). The major bus lines connecting Ulus to the northern settlement area and Kızılay to the southern settlemen area in Dikmen and Akay are proposed. At the second phase -which covers the goals for the year 2005- the construction of Kızılay-Çayyolu metro line is planned to be constructed until 2000 and Keçiören-Ulus metro line is planned to be constructed until the year 2005 (ABB, 1995, p.86). In this respect, Kızılay-Çayyolu metro line –the study area- is planned in relation to corridor type of urban development along the Eskişehir road for the first time in 1990s. For the year 2015 –which is the final target year of Transportation Master Plan- the proposed rail network is decided to be completed by constructing the Dikmen-Kızılay metro line and Etlik and Plevne extensions of the light rail system in the last phase (ABB, 1995, p.86). Furthermore, it is proposed in the transportation master plan to plan all the stations on the network so that they meet the transferring passenger's needs based on the predicted passenger volumes. So, it is inferred that not only the integration of transport and macroform planning but also integration between the different lines of the rail network and of different modes of public transportation are highly prioritized in planning studies in this period. However, it was also a period in which the investments in road network and overcross intersections as a solution to increasing traffic congestion are accelerated despite all these effort to prioritizing public transportation. There are partial changes and land speculations occured along the development corridors defined by the structural plan and the transportation master plan which are the two main plans directing the urban development and macroform, which have weaken the consistency within the plans.

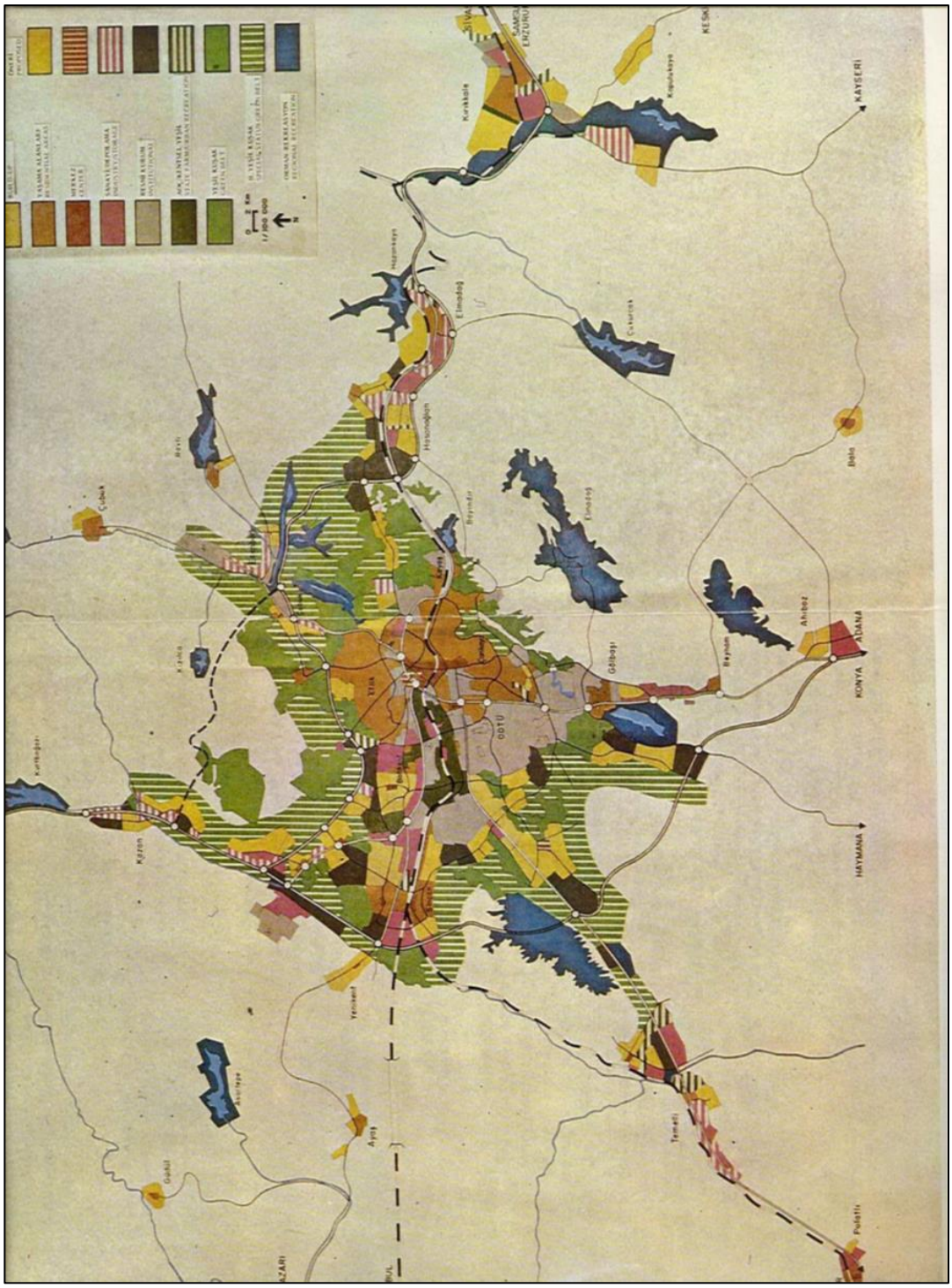


Figure 4.7 Ankara Structural Plan for 2015

Source: Ankara Büyükşehir Belediyesi (2006, p.52)

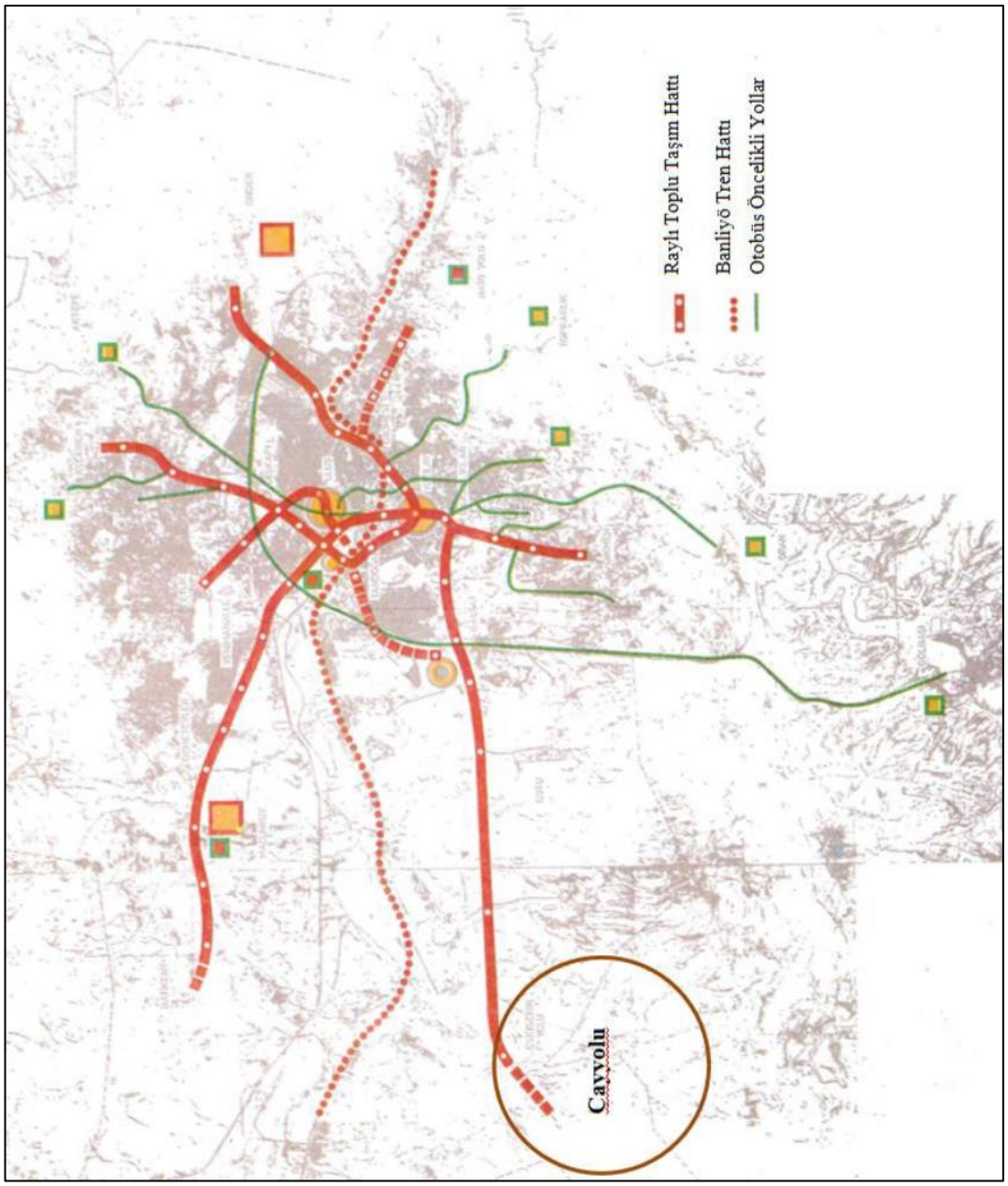


Figure 4.8 Public Transportation Network in Ankara Transportation Master Plan for 2015

Source: Ankara Büyükşehir Belediyesi (1990a)

Another master plan is necessitated because the 1990 Ankara Master Plan was limited in terms of directing urban development and controlling the urban sprawl in the southwester corridor as a result of land speculations, and the structural plan for the year 2015 was not approved and damaged by the unplanned interventions such as the construction of ring-road. Although there were a master plan for targeted to year 2025 prepared by partial studies after 1995, it could not be effective in controlling the urban development because it was not approved due to the exaggerated population projection and confusions on planning authority in those years (ABB, 2006, p.64). Alternatively, the Capital Ankara Master Plan targeted to year 2023 was approved in 2007 coming into force 25 years after the 1990 Master plan was approved. The Capital Ankara Master Plan predicted the population in 2023 as minimum 5,5 million and maximum 6,5 million. But it aimed to create a capacity for 8 million population by reserving particular areas (ABB, 2006, p.483). This plan has divided the metropolitan area into 6 separate planning regions, taking into account the natural, topographic, spatial constraints and transportation network. Each of these planning regions along the major roads and the urban rail lines that are proposed in the transportation master plan for the year 2015 corresponds the the radiants from the central area which forms the radial metropolitan macroform. The first one is central planning region covering the core region where the city's central business areas are concentrated and the housing areas that integrate with the center in line with the transportation relations and development potentials surrounding this region. The western planning region as the second one includes residential and large industrial areas along Batıkent, Eryaman, Sincan, Kazan districts which were also defined as the western development corridor in 1990 Master Plan along Istanbul road guiding the development a the main backbone. However the backbone of the western corridor after 2000s is not limited by İstanbul road but also formed by the Kızılay-Batıkent and Batıkent-Sincan metro lines planned in early 1990s and constructed in mid-1990s. Thirdly, the southwestern planning zone refers to urban development in Çankaya and Gölbaşı districts along the Eskişehir road. This corridor has been defined as the area where the land speculations are centered since 1990s and

remarkable urban development took place. The Kızılay-Çayyolu metro line, which is the subject of this study, is the backbone of the southwestern planning region in terms of the public transportation facilities. Therefore the the urban dynamics within this region are to be provided in the next parts. Fourthly the southern planning region which covers the urban development in Gölbaşı, Bala and a part of Kızılay districts along the Konya Road, is a special basin that stands out with its protection values and priorities. The eastern planing region as the fifth one includes development areas in parallel to Samsun Road in Mamak, Elmadağ and Kalecik districts, and defined as the most disadvantaged and underdeveloped region of the city in line with socio-economic indicators. Lastly, the northern planning region is the area formed by the Altındağ, Keçiören, Çubuk and Akyurt districts and the first level municipalities established within these areas, which are described as the Çubuk Basin that takes the Esenboğa-Çankırı Road as a backbone. This region stands out with its characteristics that there are important agricultural lands and catchment basins, but urban development trends and industrialization potential are developing in a way that can harm natural and environmental values. The 99 sub-regions that have defined in the 1993 EGO Transportation Study within the planning regions described were updated and 129 planning sub-regions were defined within the boundaries of Metropolitan Municipality in the context of 2023 Capital Ankara Master Plan (ABB, 2006, p.483). The transportation network and socio-spatial features within the regions are the main determining factors in the creation of sub-regions.

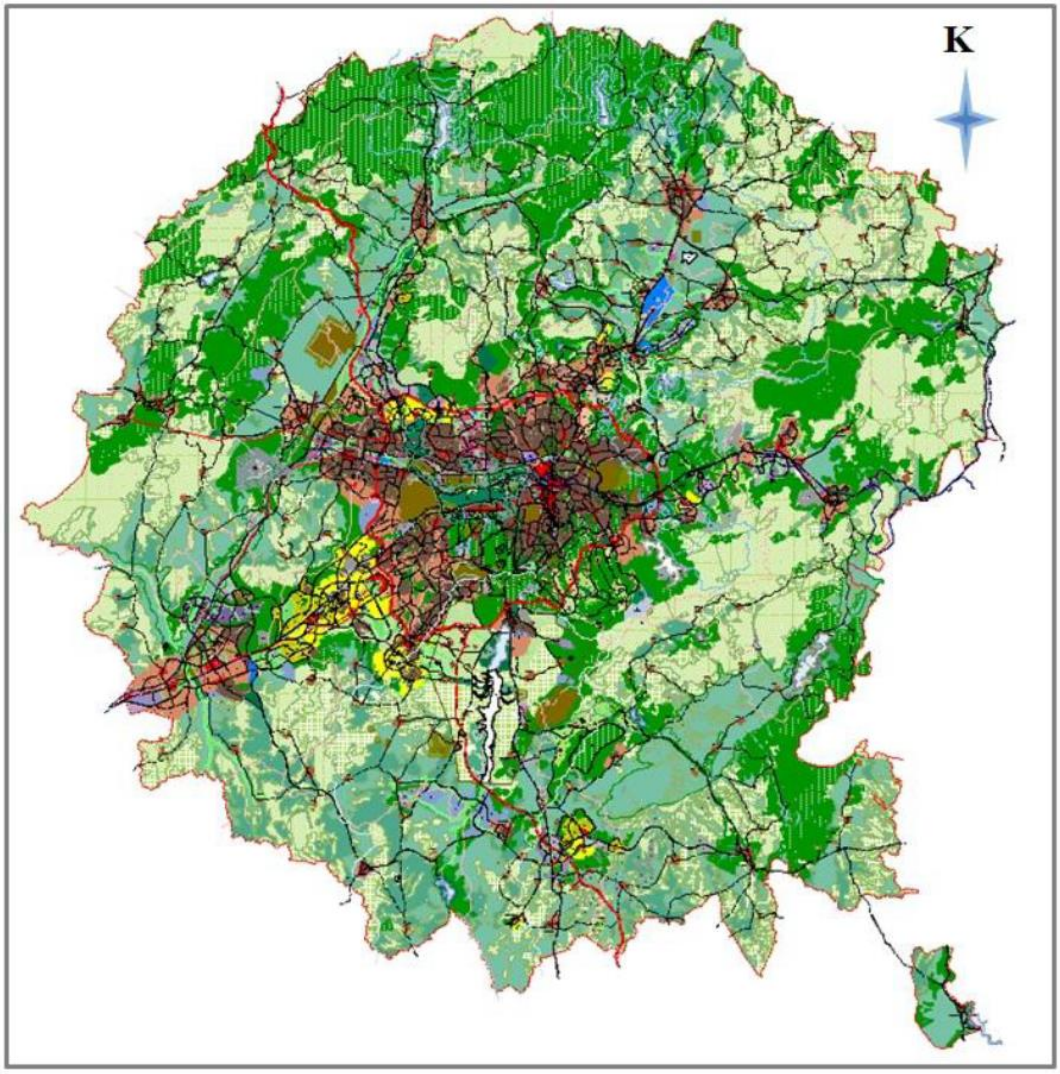


Figure 4.9 Capital Ankara Master Plan for 2023

Source: Ankara Büyükşehir Belediyesi (2006, p.747-763)

As the basis for all these urban development period the rapid population growth should also be considered in parallel with the macroform development of the city. It is an indispensable factor to understand and analyze not only the macroform, but also transportation problems and the policies employed as a solution to them.

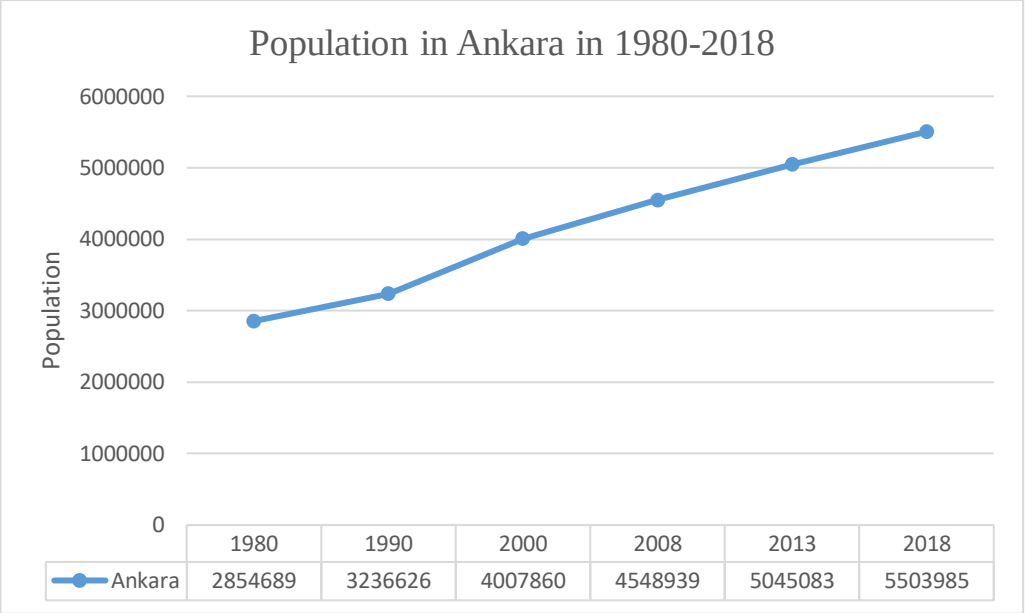


Figure 4.10 Population Change in Ankara

Source: Produced by the author based on data sourced by TÜİK

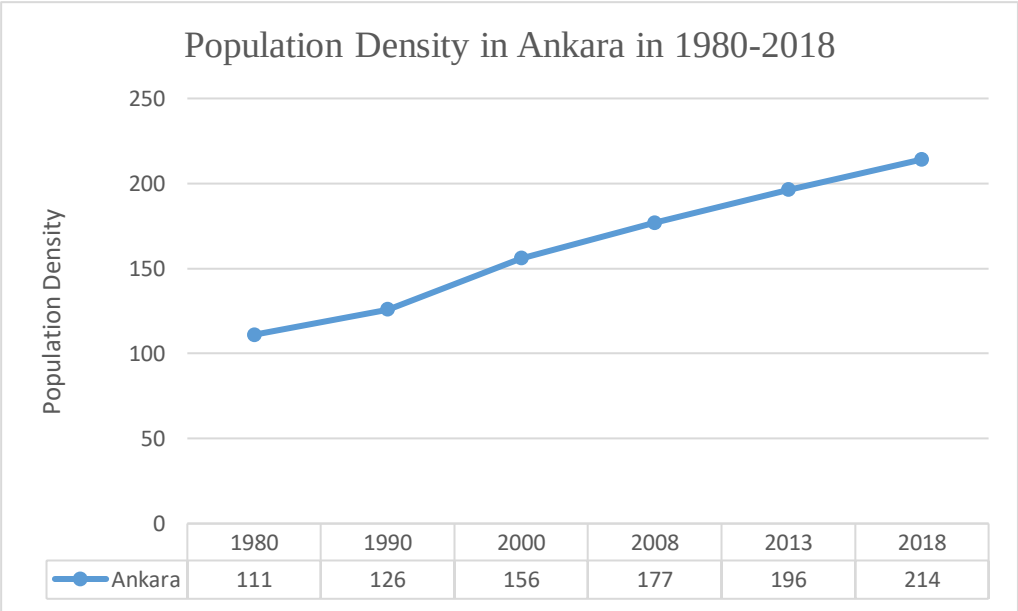


Figure 4.11 Change in Population Density in Ankara

Source: Source: Produced by the author based on data sourced by TÜİK

It is already mentioned that population in Ankara has tended to increase since its decleration as the capital in 1923. According to the graphs in Figure 4.1. and Figure 4.11 produced from the official statistics announced by TÜİK, the population has increased from 1990 to 2000 by approximately 77.000 people in 10 years (2% increasing rate) although the rate of increase slowed down after 2000. Then the population have reached to 5.500.000 in 2018, which is the minimum limit of population predicted by the Capital Ankara Master Plan for the year 2023.

In order to have a better understanding of possible impact of population increase in urban area, it would be useful to explore the graph in Figure 4.11 presenting the change in population density. It is displayed on the graph that 111 people live in one kilometer square area in Ankara in 1980 while there were 214 people living in the same size area. That is, population density per km2 is rose as a result of population growth. Not interestingly, it is expected that the number of people using urban activities in a given area, therefore the need for access to activity centers, and the demand for urban transportation will increase.

In summary, the urban problems encountered since the declaration of Ankara as the Capital could not be controlled despite all the planning efforst. Whereas the Lörcher and Jansen plans in the first years designed residential areas for settling the rapid population increase as a result of emigration within the topographic basin whereas Yücel-Uybadin plan proposed for the first time to exceed the topographic basin and directed urban development towards the west along Istanbul Road. Although the main urban development in those years took place in line with the basic recommendations of these plans, they failed to control the growth because the population growth was much faster than expected. In 1970, Breu of Master Planning in Ankara was established and a comprehensive master plan was prepared for 1990. This plan mainly envisaged the development of the city along the western and southwest corridors outside the basin. The western development corridor was designed by this plan as including dense residential areas and large industrial areas while the southwest corridor is designed as university and low-density small housing cooperative areas except for the public and government offices. However, the urban

development in the southwest corridor in the period of 1970s-1990s has been occured in a pattern of urban sprawl by going beyond the planing decisions due to the land speculations and administrative obstacles to the implementation of the plans in those years. The studies for Transportation Master Plan in Ankara –the projects and feasibility etuds of which was under study since 1970s- has started in the late 1980s due to the increased urban transportation problems. The transportation network consisting the metro lines and bus routes that were in the feasibility stage in the 1980s was officially decided by Transportation Master Plan approved in 1994. However, a structural plan targeted for 2015 was prepared simultaneously with the transportation master plan because it nececitated an approval of an urban macroform as a basis for transportation decisions. These two plans formed the basis of Ankara's current macroform and transportation network with through decisions they produced in parallel to each others. Approximately 25 years after these plans, the 2023 Capital Ankara Master Plan adopted the radial macroform determined by the 1990 Master Plan and propose to decentralize urban development to the west, southwest and newly emerging north, south and east radiants along to the major transportation axes including both the major roads and urban rail lines decided by the Transportation Master Plan approved in 1994.

It is considered as essential to get a knowledge of the formation of urban macroform in Ankara and changes in the transportation network in relation to each others for comprehending Kızılay-Çayyolu metro line as a remarkable case for the problem area asserted at the beginning of the thesis and for concluding on how it has affected the accessiblity of the urban development area of Çayyolu corridor.In this context, the urban dynamics of the Çayyolu region and the spatial and technical features of the metro line will be given in the following parts.

4.2.2 Public Transportation Policies and Travel Behaviours in Ankara

Ankara was a city with a population of 90.000 where the rate of motorized trips was 15% in the beginning of 1930s. However, this rate reached 80% within the total trips made by a population of 2,5 million in 1980s (ABB, 1995, p.6). The rapidly increasing demand for public transportation in this period has been tried to be met by a public entrepreneurship, whose recources could not be organized at the same pace.

At the beginning of the 1930s, the only public transportation is the suburban line between Ankara –the station- and Kayaş which has 9 km length (ABB, 1995, p.6). This line accelerated urban development by increasing the accessibility of Cebeci, Mamak and Kayaş regions. The authority for operating bus, minibus, and electric tram in Ankara was assigned to the Municipality in 1930 but the Municipality was able to attempt for the first time in 1935 by establishing Ankara Municipality Bus Administration Breau. Then 100 busses were imported from the Soviet Union which served in 15 lines with an average length of 6 km (ABB, 1995, p.6). There was a surplus in public transport in the late 1935 when the share of motorized travels in total trips did not exceed 22% due to the urban form. The share of municipal busses on these trips was 60% (ABB, 1995, p.6).

Provision of public transportation could not be maintained in 1940s and these years have been the beginning of the shortage in public transport as the increase in the demand for motorized travel has accelerated. As a result of the vehicle fleet being damaged by a fire in 1946, the first dolmush lines were formed in the busiest routes such as Ulus-Cebeci, Cebeci-Sıhhiye, Ulus-Ministries, etc. The negative effects of the fire was diminished thanks to 10 trolleybusses putting into operation in 1947 to an extent. The share of public transportation in these years has fallen to 50% of the total trips (ABB, 1995, p.6).

The municipality has expanded and renewed the vehicle fleet in the first half of the 1950s. The number of passengers carried on EGO lines increased by 2,7 times but

the share of public in public transport provision has increased only to 65% because the private enrepreneurs have also expanded their fleets and the number of passenger they carried in these years (ABB, 1995, p.7). In the second half of the 1950s, EGO buses served the new developing areas of the city leaving the central areas to private entrepreneurs. Public share within the whole public transportation provision fell below 50% in this period (ABB, 1995, p.7).

The public share fell to 30% and the number of passengers decreased in 1960s as the EGO vehicle fleet and the number of the bus lines remained largely constant in these years (ABB, 1995, p.7). Increase in the share of minibusses as a result of starting minibus vehicle production in Turkey is one of the reasons for this. In addition, the station dolmushes as an option for public transportation have emerged as a result of banning of minibusses from Gazi Mustafa Kemal and Atatürk Boulevards. In the first half of 1970s, both the vehicle fleet of Municipality and private entrepreneurs did not grow significantly, which caused to meet the demand by carrying higher number of passengers with fewer vehicles. The average waiting time for the busses has increased and the demand in morning and evening peaks are spreaded over a larger time period by shifting the working hours (Vural,2019, p.3). Another important change in transportation policies in 1970s is rapidly increasing number of private cars in urban traffic as a result of automobile factories producing. Consequently, the share of private cars in urban journeys reached the share of EGO vehicles in 1975 (ABB, 1995, p.7).

The early 1980s were the years when the development of public transport ceased due to the stabilization measures taken in the economy. The most important development of this period is the participation of Private Public Buses in urban passenger transportation in 1982 (ABB, 1995, p.7). The commercial activities of station dolmushes were strictly prohibited and they were allowed to turn into 14-person minibuses, which resulted in formation of new minibus lines within the settlement areas in addition to main lines along the radiants between the central area and residential areas (ABB, 1995, p.7). At the end of the 1980s, attempts were made to lift Private Public Buses (ÖHO). The three main reasons for this are as follows: ÖHA

attracts the passenger, who was previously carried by EGO buses, but does not offer additional capacity since it does not carry new passengers. Secondly, they have shifted to the most profitable lines over time although they have been established to serve places where EGO and minibus service are not enough. Thirdly, they work at times that will provide them with full occupancy but they do not work at other times, which indicates that there was a competition between the urban transit providers within the same network (ABB, 1995, p.6). However, the ÖHO has not been removed and still has a large share today.

Coming to the 1990s, urban rail system projects were initiated as bus transit systems were insufficient in meeting the transportation demand of growing population in Ankara. In this context, Ankaray light rail line with 8.5 km and 11 stations between Dikimevi-Aşti was opened in 1996. In 1997, a 14.5 km Metro line with 12 stations was opened between Kızılay and Batıkent (Vural,2019, p.4).

The works for constructing further infrastructure for urban rail systems continued in early 2000s and the metro lines between Batıkent-Sincan as an extension of Kızılay-Batıkent line, and Kızılay-Çayyolu metro were put into operation in 2014 which are followed by Keçiören-AKM metro line started servicing in 2017. The first cable car which connects Şentepe district to Yenimahalle metro station was also put into operation in 2014 (Vural,2019, p.5).

Having put the Ankaray and metro lines into operation, the buses formerly operating on these routes were changed into a network of bus lines feeding the rail stations Then the overall network of public transportation based on the urban rail system as the primary transportation lines along the main corridors while the bus transit sytem is planned as the secondary mode to provide access from settlement areas to rail stations when considering the plans and spatial network. It is also suggested by the Transportation Master Plan that all the stations to be transferred from either the commuter rail, bus lines or personal otomobiles will be determined an required area for transferring facilities such as bus transfer areas, pedestrian connections, parking

areas will be allocated around the stations when the implementation projects are being prepared (ABB, 2015, p.100).

The 1994 Transportation Master Plan also determined that the bus system functioning as a feeder for rail and suburban trains increases the importance of the bus system's future role in urban passenger transport. The estimates of the passenger transport shares of the rail transit system and the suburban system are based on the assumption that a good integration with buses to be operated as a feeder will be achieved. It is suggested that the three factors that will ensure such an integration are as fallows: Providing appropriate transfer areas, increasing the bus service frequency and enabling a better service schedule, integration of the ticketing system of these two modes (ABB, 2015, p.76).

The Capital Ankara Master Plan targeted for 2023 has also identified strategies for urban transportation and some particular intervention areas. Firstly, it is emphasized that revising the road projects such that the demand for automobile use in certain axes is managed rather than expanding the road infrastructure -which could not accomodate the increasing number of vehicles in urban transportation- is necessitated to minimize the transportation problems. It is also recommended to restrict the automobile dependent transportation within the central city and to improve the public transit facilities by investing in metro, commuter rail, and other public transit modes as well as designing pedestrian zones around the stations. The southwest corridor which has been experiencing a rapid urban development is particularly pointed out by the Master Plan as the axes where an urban rail line is needed not to meet an existing demand but to direct both the demand for urban development and the travel behaviours along the corridor which are mostly automobile-dependent. The plan regards it essential to ensure that this rail line could reach the Dodurga central area which requires a route along southern and western sides of the Kızılay-Çayyolu line had been under construction (ABB, 2006).

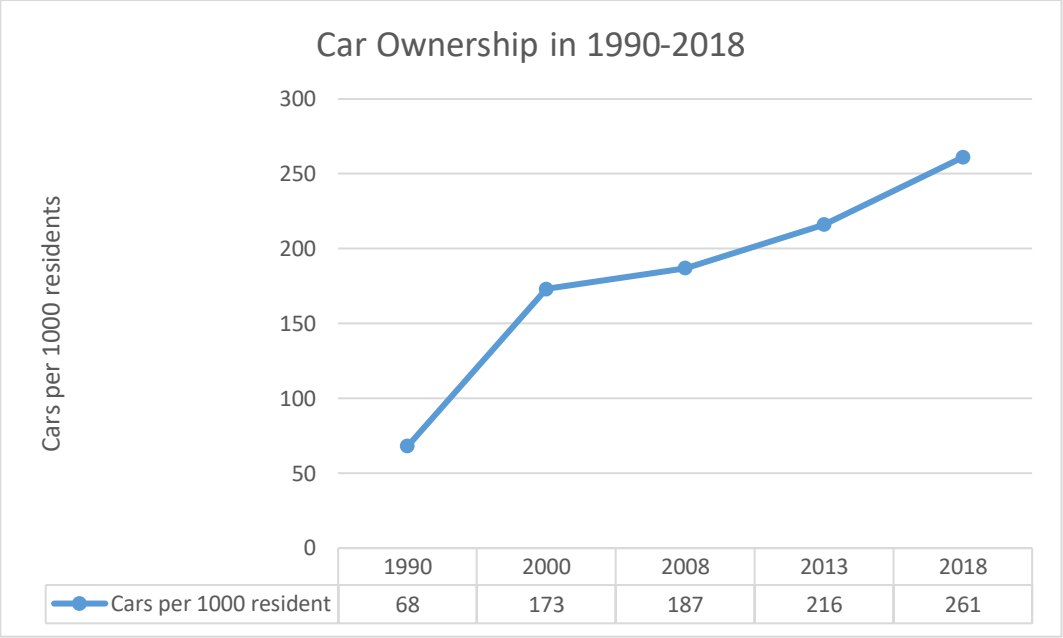


Figure 4.12 Change in Car Ownership Rate in Ankara

Source: Produced by the author based on data sourced by TÜİK

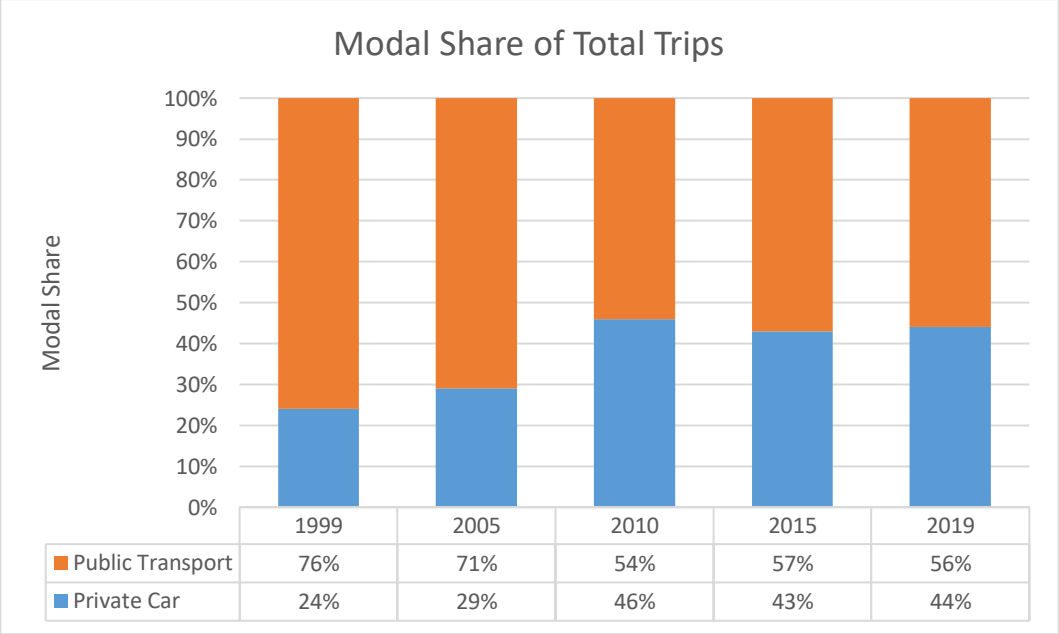


Figure 4.13 Change in Modal Share of Total Trips in Ankara

Source: Produced by the author based on data sourced EGO

Table 4.1 Modal Share of Trips by Public Transit in Ankara

	1999	2010	2019
EGO BUSSES	22,5	29,4	20,1
ANKARAY	5,2	4,4	3,4
METRO	5,2	7,1	9,7
COMMUTER RAIL	3,0	2,6	1,3
MINIBUS-DOLMUS	29,6	29,2	27,7
SERVICE VEH	20,5	14,7	21,9
PRIVATE PUBLIC BUSES	6,0	7,5	6,5
PRIVATE TRANSIT VEH	5,4	3,5	3,2
2-STOREY BUSSES	2,5	1,6	0,0
CABLE CAR	0,0	0,0	0,2
DISTRICT BUSSES	0,0	0,0	1,3
PRIVATE SERVICE VEH	0,0	0,0	4,8
TOTAL	100,0	100,0	100,0

Source: Produced by the author based on data sourced EGO

In summary, the demand for urban transportation in Ankara –where the rate of motorized travels was very low (15%) and majority of the trips were on foot in the first years of being capital- has significantly increased especially in the period of 1930-1980 as a result of rapid growth in population and urban development. The public transportation policies with the priority for bus transit could not meet the increasing demand . Therefore, the private entrpeneurs such as private public busses, minibusses, dolmushes, etc. were invited to the sector to supply public transportation service. However, the emerging competition among the public transit providers including the municipality made it much more difficult to plan the public transportation. Then the Transportation Master Plan targeted for 2015 was approved in 1994 by which the basis of the current transportation network of the city were decided. This plan hav given rise to shift in public transportation strategies from bus oriented public transportation to urban rail system oriented public transportation. Accordingly, a comprehensive rail system network and integrated bus lines are planned to be completed in 3 stages between 1995-2015.

However, car ownership rate and use of automobiles in urban transportation have been increasing as a result of the national economic policies on the one hand and

urban development along the corridors radiating from the central area as well as the investments in road network rather than public transportation on the other hand despite the planning efforts to improve public transportation services as a solution both for urban transportation problems and out-of-control urban development. There is also no increase in the rate of public transportation and no decrase in the rate of car ownership in 2018 although the Transportation Master Plan targeted 2015 had planned investmennts in rail system prioritized urban transportation and finally the Capital Ankara Master Plan targeted 2023 had proposed policies for promoting the public transportation and especially an alternative metro line to Dodurga along the soutwest development corridor.

The fact that the car ownership has been increasing and share of public transportation in total trips has been decresing from the early 2000s and the rate of metro travels is less than 10% whereas the rate of bus travels is higher than 20% despite all these plans to promote a rail network oriented public transportation system in Ankara is the main motive to explore the accessible geography that the integration system of Kızılay-Çayyolu metro line and feeder bus lines creates within a travel time constraint and to search for suggestions for improving its capacity of providing higher accessibility from the city planning perspective.

4.2.3 The Case of Kızılay-Çayyolu Metro Line (M2) in Ankara

The metro line from Kızılay –the city center- and to Çayyolu –the residential area at the end of the southwest development corridor- is planned by the Transportation Master Plan targeted the year 2015 as an urban rail line with the capacity of 40.000 passengers per hour. It is planned to be put into operation until 2000 as the second phase of Batıkent-Kızılay metro line (ABB, 1995, p.86).

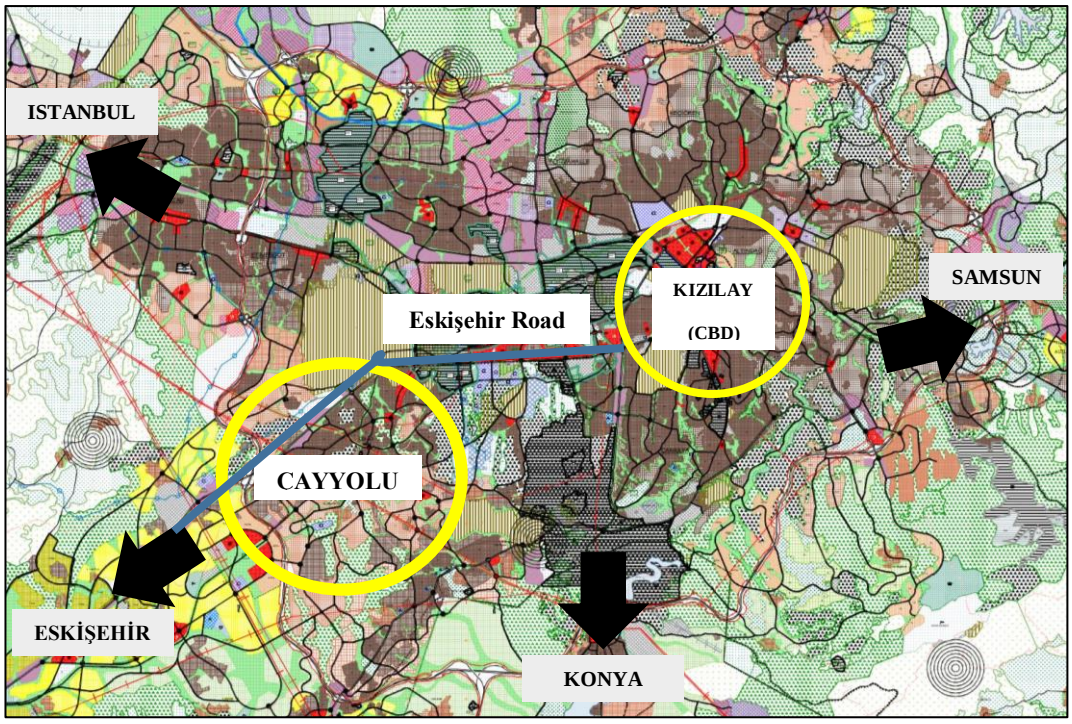


Figure 4.14 Map of Kızılay-Çayyolu Urban Development Corridor

Source: Produced by the Author based on Map Sourced by ABB, 2006.

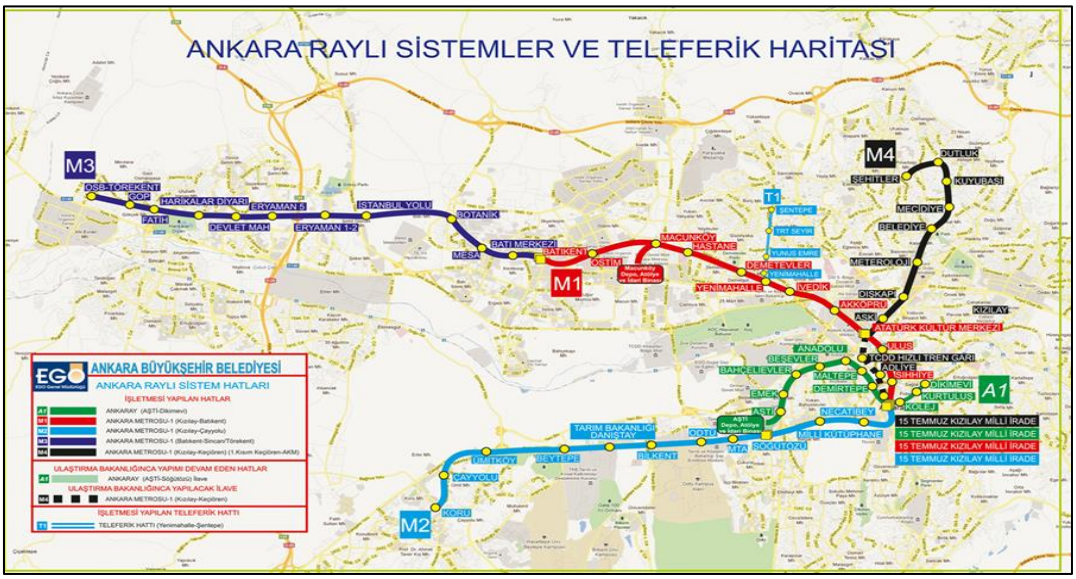


Figure 4.15 Map of M2 in Urban Rail System Network in Ankara

Source: EGO, 2019a

The 1995 Transportation Master Plan also determined that the estimates of the passenger transport shares of the rail transit system and the suburban system are based on the assumption that a good integration with buses to be operated as a feeder will be achieved (ABB, 1995).

The Kızılay-Çayyolu metro line, which is planned to be completed until 2000, was put into operation on 13 March 2014. Being completed approximately 14 years later than the planned, the line with a 16,590 meters length includes 11 stations between Kızılay –the departure station- and Koru –the arrival station. The integration of EGO busses -which had formerly been serving in between Kızılay-Çayyolu region- as the feeder lines to Kızılay-Çayyolu metro line which functions as the primary public transit line along the corridor was put into operation in five months later the openning of metro service, in August, 2014. Having been integrated to the bus lines that provides access from settlement areas to the stations rather than transporting passengers in alternative routes, the average daily passenger number transported by M2 line have reached approximately 90.000 in 2015 and 120.000 in 2019 (EGO, 2019b).

There were 7 bus lines serving between the Çayyolu region and Kızılay before the integration between Kızılay-Çayyolu metro line and EGO busses as presented in Figure 4.16. These bus lines travelled to Kızılay along the Eskişehir Road after following varying routes within the settlement are in Çayyolu, Ümitköy, Koru districts (Aydemir, 2015). However, the EGO bus lines are removed after their integration as the feeder lines to Kızılay-Çayyolu metro line which functions as the primary public transit line along the corridor in 2014.

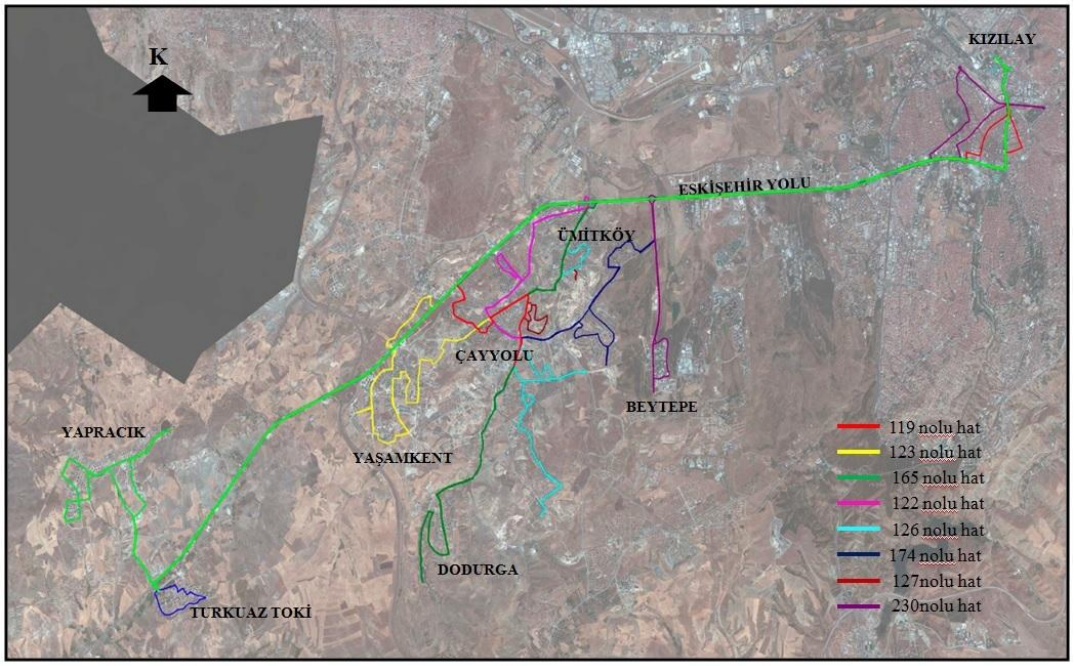


Figure 4.16 Bus Lines in Kızılay-Çayyolu Route Before the Integration

Source: Aydemir, 2015, p.59

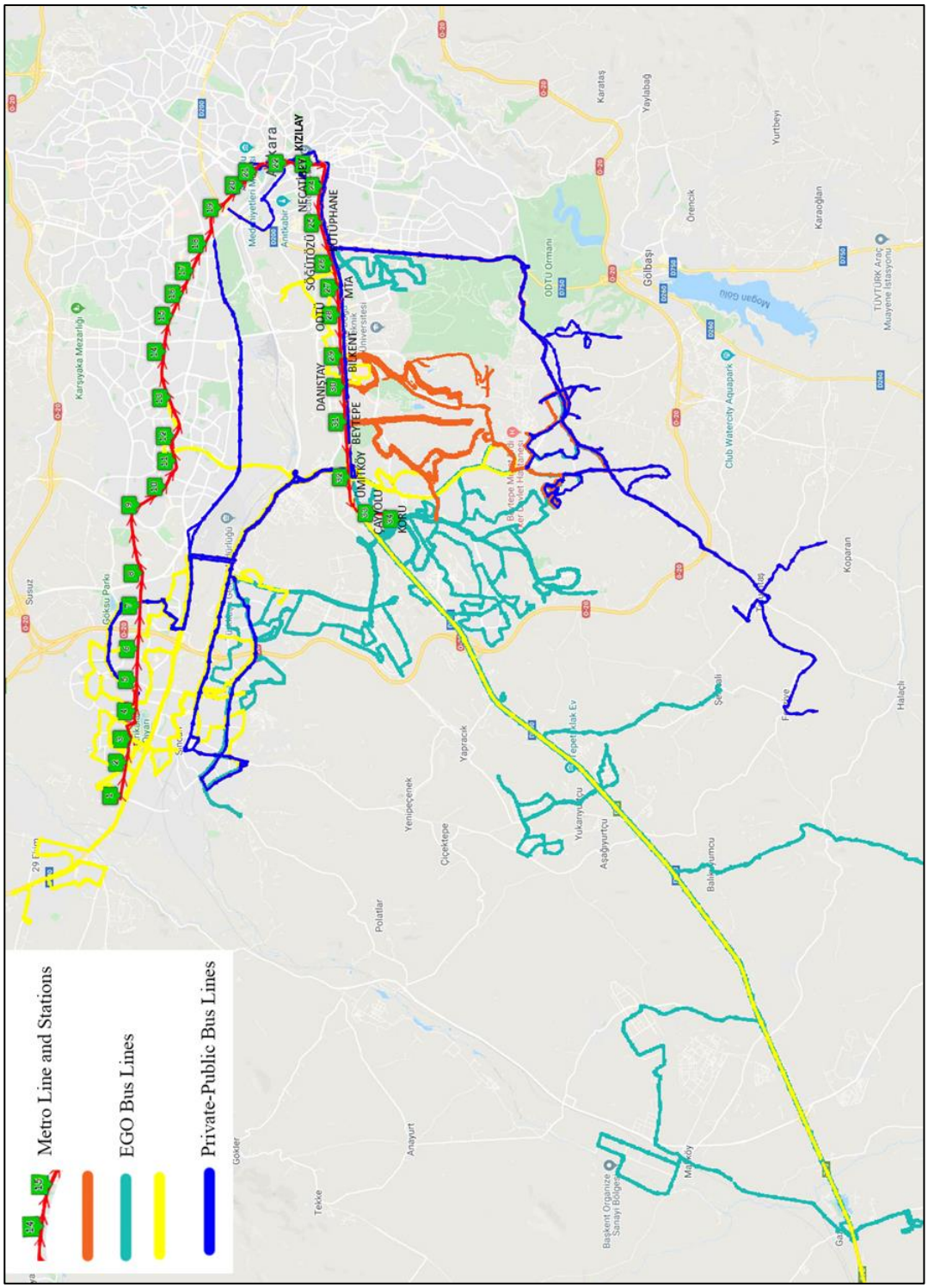


Figure 4.17 Kızılay-Çayyolu Metro Line and Bus Lines After Integration

Source: Produced by the author based on data sourced by EGO, n.d.

The train services on the Batıkent-Kızılay metro line (M1) and Kızılay-Çayyolu metro line (M2) were integrated into a single line which does not necessitate transfering between the vehicles at the beginning of the 2019 when the current study was ongoing. So the segment of Kızılay-Koru with the 11 stations along a line of 16 km and the integration of this segment with EGO busses along the southwest development corridor comprises the context of this study.

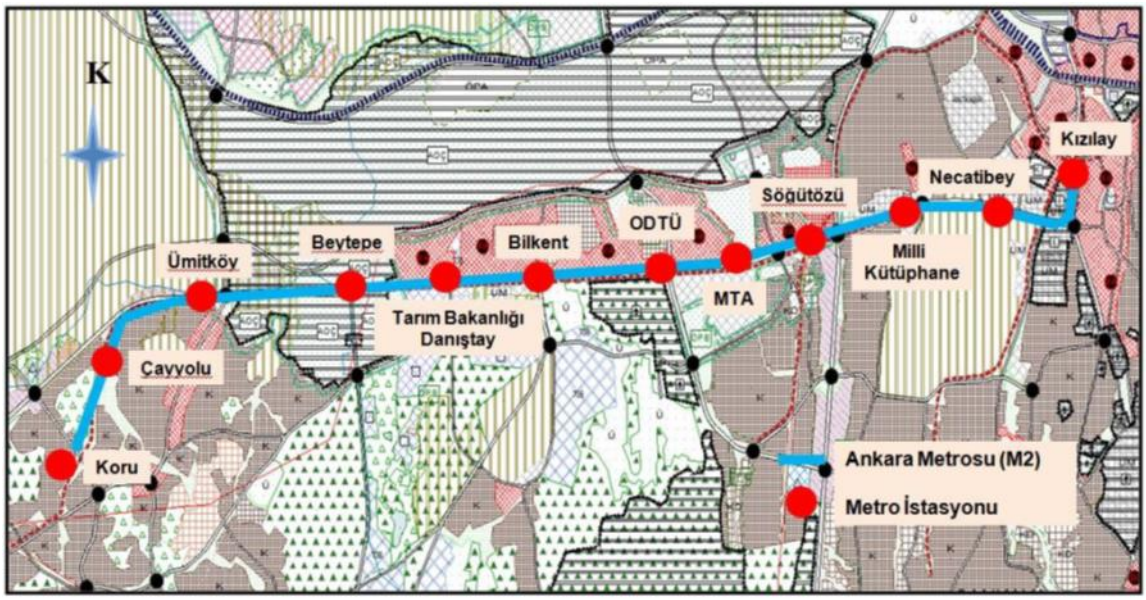


Figure 4.18 Kızılay-Çayyolu Metro Line and Stations

Source: Aydemir, 2015, p.56

The map in Figure 4.17 above shows the metro line between Batıkent and Koru through Kızılay and the EGO bus lines integrated to Kızılay-Çayyolu segment of the metro line as well as the private-public bus lines along Eskişehir road which serve alternatively to M2. There are feeder EGO bus lines servicing between the settlement areas and 7 stations out of 11 on M2 except the Necatibey and Milli Kütüphane stations that are located in and around the central area, and ODTÜ and Çayyolu stations. Although the EGO busses are integrated to M2 at 7 stations in total, Koru and Ümitköy stations both of which serve to the residential areas are the

major transfer stations on the line. Particularly, there are 22 feeder EGO bus lines serving to a significantly large area from Koru station and 407 arrival bus stops along these lines, and 15 EGO bus lines providing access to the surrounding area from Ümitköy station and 344 arrival bus stops on these lines. Following the Koru and Ümitköy stations, there are 3 feeder bus lines linked to each of Bilkent, Beytepe, and Söğütözü stations, 2 lines linked to Danıştay stations, and 1 line linked to MTA station, and 205 arrival bus lines along these lines in total.

However, there are also private public buses that are still in operation in 2020 and dolmushes serving in the alternative routes to metro line and service area of feeder bus lines even though EGO bus lines between Çayyolu region and Kızılay are removed and integrated to M2 line as feeders.

4.3 Data Requirement & Collection

Having previously described that the information of "space" and "timing" are the two types of data needed for defining control points in a space-time path analysis. The schema below shows the basic elements of anlysis which also represents the required data. Accordingly, the departure station as the space for train waiting activity, the arrival stations as the space for getting off the train, the departure bus stops as the space for bus waiting activity, and the arrival bus stops for getting off the bus and changing the mode into walking are the control points in travelling from Kızılay to each possible destinations in the study area. The movements between the control points both in space and time are to be the segments of movement path that will be defined by travel time and direction creating the space-time path. The spatial and descriptive data needed for defining the control points and movements are obtained from two major data sources: EGO urban transit information system and Google transit.

4.3.1 Spatial Data of Stations and Stops

As the initial step of data construction, the location information of both metro stations and integrated bus stops are extracted from the online information system (EGO, n.d) of EGO, transit supplementer body of Ankara Greater City municipality. The spatial data obtained is digitized as points on a GIS-based map as the online information system do not provide an interface for individual data processing. Point-based spatial framework is utilized rather than aggragate zonal framework so that all locations are presented as distinctive units in space and there will be no filtration of an amount of travel time cost. Moreover, the spatial information of control points are represented by the stations and stops in the form of points and the movement paths are supposed as invisible connections that will be defined by the duration and direction. It is because generating the route data is extremely time consuming and complicated in terms of the analysing algorithm. The descriptive data for each stations –such as the name, ID, etc.) are digitized as attributes of related points in ArcGis.

4.3.2 Schedules and Waiting Times

Secondly, the schedule information of both trains and feeder bus lines are also obtained from urban transit information system of EGO (EGO, n.d). The data of departure times for trains and each feeder bus lines constitutes the base for calculating the waiting time for each representative travels. The two factors determining the waiting time either for trains or busses are the time when the passenger arrives at stop and the servicing headway. Since the schedule is arranged according to travel demand in days of the week and time of the day, waiting time for a particular service is not static but varies accordingly. Therefore, conducting the analysis based on schedule-based data of travel time and waiting time is to be useful.

The average headway of feeder bus lines within 2-hours period, including an hour before and after the peak or off-peak hours at which the representative travels will

be generated, are employed in determination of the waiting times. There are two reasons for depending on a two-hour time interval. The first is that the schedule of any bus line is much variable that designating a frequency requires appreciation of an average headway for a certain time interval. Secondly, consideration of the waiting time specific to an instance –which may either be quite recent or distant to the next departure time- might mislead all the data. In order to capture a more accurate set of data, the average headway within the 2-hours interval is calculated for each bus lines and the mean headway for each is regarded as the waiting time. In the case of multiple bus lines passing through a particular bus stop that is assigned as a destination, whose travel times are roughly the same, an overall average headway is calculated for that specific journey. It is achieved by dividing the specified time interval, which is 120 seconds, by the total number of bus services within the interval.

4.3.3 Travel Time

The third group of data needed includes in-vehicle travel times of both rail travels from Kızılay to each stations of metro line, and bus travels from interchange stations to each bus stops for each lines. Because this type of a data is currently unavailable, travel times are obtained through generating representative journeys for each destination stops at peak and off-peak hours by means of Google Transit application.

Google transit is a public transportation planning tool that combines the static data of transit routes, stops, and schedules with the power of Google maps and accessible to Google users. Once the participating transit agencies share their static data and add updates, all possible public transportation options and the best routes for getting a specified origin to a specified distance are revealed by the application. It also gives the departure times, the stop information, travel time, etc. Furthermore, it predicts the traffic volume and average speed on the network through collecting the GPS signals that android phone users automatically send. Thus, it provides a real data of travel time that is sensitive to temporal changes in the traffic volume on the specified

route. Therefore, it is an advantage to obtain travel time data from Google transit for relativelly small samples as it is in this study.

For presenting the data frame accurately, it is necessitated to assert that only the EGO busses are included as the feeder bus lines because private bus lines do not have the characterisitcs of feeder lines. They are in the form of longer lines connecting some parts of the city to the centroid although they are also integrated to the metro stations. Since the stops up to 800 meters from the stations are accessible by maximum 10-mins walking, travel time for accessing these stops are considered as the walking time.

4.3.4 Walking Time

Transportation from any stations or stops to activity location or vice versa is needed at the beginning or end of a journey. In addition, travel time of egres from the station and access to the exchange bus stops is another major interruptions that are exposed to in mutli-modal integrated transit systems. The mode utilized for these movements is walking for the Ankara case. So the walking time for access and egress to the stations and stops is needed. Because it is assumed that all the journeys are originated from Kızılay metro station, access to there is excluded from the analysis. Yet, the walking time to egress from the destined station and to access the integrated bus stop is critical as a movement path segment, data of which is also obtained via Google transit for all stations individually. Finally, it is also necessitated to walk from destination stop to the activity location –which is mostly the home. However, data for walkin time from the stops to the final destinations –mostly the homes- is not possible to obtain because the infinite number of activity locations are not assigned as destinations to the representative journeys. Instead, the maximum walking distance (800 m) and corresponding walking time (10 min) –the remaining time if it exceeds the travel time budget- is added to each journey.

In summary, the locational data of stations and stops, schedule information, travel time, and walking time are the four primary data groups needed for each representative journeys. The locational data of stations and stops stands for the spatial aspect of the control points while the others are inputs for defining the time axis of both the control points and movement path segments. EGO urban transit infromation system and Google transit are the two sata sources that are freely accessible. However, they do not provide the data in a ready format, but necessitates querying each single data for each specific journeys at each specific time. Some of the rough data is exploited as input for generating further data while the some is directly included in the analysis. Hence, a comprehensive data storage and data management base is provided. It is a type of extended impedance matrix which consists of Kızılay as the single origin and 946 feeder bus stops as destinations. Although Kızılay –the city center- is the unique origin within the scope of the study, there are three lines in the extended matrix because the each stands for times of the day, which are 5.00 pm as the evening peak and 2.00 pm as the off-peak in a weakday, and 2.00 pm in Sunday. Similarly, the raws are also extended such that they not only includes the overall impedance but also the source of the impedance such as waiting, walking, etc.

Table 4.2 Data Management Matrix for Travel Time as Impedance Value

	STOP ID (1)					STOP ID (2)					STOP ID (3)				
KIZILAY (M2) (17:00)	wt	trv	wlk	wtbs	trvbs	wtng	trv	wlk	wtngb	trvbs	wtng	trv	wlk	wtngb	trvbs
	2	19	2	10	4										
	37					0					0				
KIZILAY (M2) (14:00)	wt	trv	wlk	wtbs	trvbs	wtng	trv	wlk	wtngb	trvbs	wtng	trv	wlk	wtngb	trvbs
	3,5	19	2	15	4										
	43,5					0					0				
KIZILAY (M2) (14:00 SUN)	wt	trv	wlk	wtbs	trvbs	wtng	trv	wlk	wtngb	trvbs	wtng	trv	wlk	wtngb	trvbs
	4	19	2	10	4										
	39					0					0				

Source: Produced by the author

4.4 Analysis

4.4.1 Determination of Accessible Geography

The first part of the analysis consists of determination of accessible geography at peak and off-peak hours in a weekday and in Sunday under three different travel time budget assumptions. So, the locational data of metro stations and bus stops are digitized on a real basemap on Arcgis 10.2 as the initial step so that it becomes ready for spatially analysed. As the space-time path analysis necessitates the control points and the unvisible path segments that connects them in space and time, the stations and stops form the primary data set rather than a network data. The outward stops are included and inward stops are excluded in data set because the return journeys are to be analysed.

The stops of feeder bus lines are digitized under unique shapefiles for each station to which they are connected. The reason is that some stops are passed through by more than one lines -each of which is connected to different metro stations. In other words, a bus stop is reached by transferring from alternative metro stations to alternative feeder bus lines. Therefore, the same arrival stop could be included more than once –in order to avoid data loss- depending on the metro stations to which they are connected. Thus, a location could be captured in the limits of accessible geography by means of one alternative route whilst it might not be accessible by means of another alternative route.

The data collected and managed in the expanded matrix is transfered into Arcgis as attributes of each destination points –the stops of feeder bus lines. To do this, data of train waiting time (WTNm), travel time by train (TRVm), walking time from train to bus (WLKNG), bus waiting time (WTNb), travel time by bus (TRVb) at 5.00 pm (WK17) and 2.00 pm (WK14) in a weekday, and 2.00 pm on Sundays (WKN14) are entered as attributes for each single stops. Having transferred data into attribute tables, two groups of further data is generated via Arcgis functions. The first one is

the total cost of travel time for accessing the each stops –that is the summation of waiting, travelling, and walking times. The second one, on the other hand, is the walking distance and times from the arrival stops to activity spaces –which are the final destinations. There are two criteria in determining the latter: The difference between assumed travel time budget and travel time cost spent on accessing to the arrival stop, and the maximum walking distance of 800 meters –corresponding to 10 minutes walking. If the difference is negative then the stop is out of scope because it is not in the limits of accessible geography under the travel time budget assumption. If it is equal to zero meaning that the budget allows accessing to the arrival bus stop, then there is no further time for walking from stop to the final destination area. In the case of the difference is greater then zero, there are two options for walking time and distance:

If the remaining budget is greater than 10 minutes, which is the maximum walking time, up to the 10 minutes of it is accepted as the walking time from arrival stop towards the final destination. Accordingly, an area of 800 metres from the arrival stop –corresponding to 10 minutes walking- is added to the accessible geography under the assumed travel time budget. The primary reason is not the travel time budget but the maximum limit of walking time which is a personal constraint. If the remaining budget is lower than 10 minutes, then it is directly accepted as the walking time and the corresponding walking distance is added as a part of accessible area under the travel time budget. This algorithm is run by means of Arcgis tools seperately for each arrival stops and for specified times in weekdays and in Sunday.

As the first part of the analysis, the geography that is accessible under three different travel time budget assumptions is to be put forward through spatial analysis of gathered and produced data. For this purpose, the arrival stops the cost of accessing to which is smaller than the available travel time budget are determined through Arcgis functions.

This selection presents the bus stops that are accessible under the given travel time budget. In other words, it is a point-based data including only the accessible bus stops

and it is far from being a spatial data covering the area that can be dispersed by walking from bus stops. For this reason, the arrival bus stops are buffered by the radius of maximum walking distance available under the given travel time constraint, as the next part of the analysis. That is, the area that can be accessed from the arrival stops by walking for remaining time from the assumed budget are defined. The overall area covered by the buffers represents the geography that is accessible from Kızılay by means of the metro line and its feeder bus lines under the given travel time constraint. The maps showing the accessible geography under three different assumptions of travel time budget in peak and off-peak hours in weekdays and in Sunday are present below: The maps aim to shed light on the issue from the two sides: The first is how the accessible geography identified on peak and off-peak hours in a weekday and off-peak hours in Sundays differs under a fixed busget of travel time. The second, on the other hand, is how the accessible geography is differently shaped on a fixed day and time under three different assumptions of travel time budgets.

4.4.1.1 Spatial Measures of Accessible Geography

4.4.1.1.1 Accessible Geography under Fixed Travel Time Budgets

As the initial step, the maps representing the accessible geography under fixed travel time budgets are produced to evaluate how it changes on different days of the week and different times of the day although the physical infrastructure is constant. In doing so, overall accessible area that is detected through processing the physical and operational data of the system composed of the metro line and feeder bus lines in peak (5 pm) and off-peak (2 pm) in a weekday and off-peak (2 pm) in Sundays are visualized and compared. The comparison is repeated for fixed travel time budgets of 30 minutes, 45 minutes and finally 60 minutes.

The metro line from OSB (Organized Industrial Zone) to Koru through Kızılay (the city center) is represented by the red line on the maps. Although it was comprised of

two seperate lines integrated at Kızılay station, they have connected and become a single line while the current research was ongoing. Therefore, not the all of the line but only the Kızılay-Koru segment and its connections with busses is examined within the scope of the thesis.

The stations on the metro line are marked with red dots. The stops of the feeder bus lines that are connected to the stations are also represented by dots. However, only o few of these stops are within the accessible area, which are therefore shown in bold dots. The remaining bus stops which are out of accessible area whown in light dots. Thus, it can be observed what amount of bus stops are within the boundary of accessible area and how this area expands under the assumed travel time budgets of 30-45-60 minutes.

The circles in different radius around the bus stops stand for the areas that can be accessed by walking from these bus stops. The walking areas around each bus stops accessible in the fixed travel time budget essentially creates the overall accessible geograhy. The bus stops which do not have a walking buffer around but are located within the accessible area are the stops the access time to which is exactly equals to the given travel time budget.

Additionally, the circles that are dashed in orange show the walking area around each metro stations. However, the areas that can be reached by walking from the stations without transferring to busses are not included in the evaluation maps since the aim of this thesis is to explore how much the integration of Kızılay-Koru metro line and feeder bus lines can cope with the urban geography.

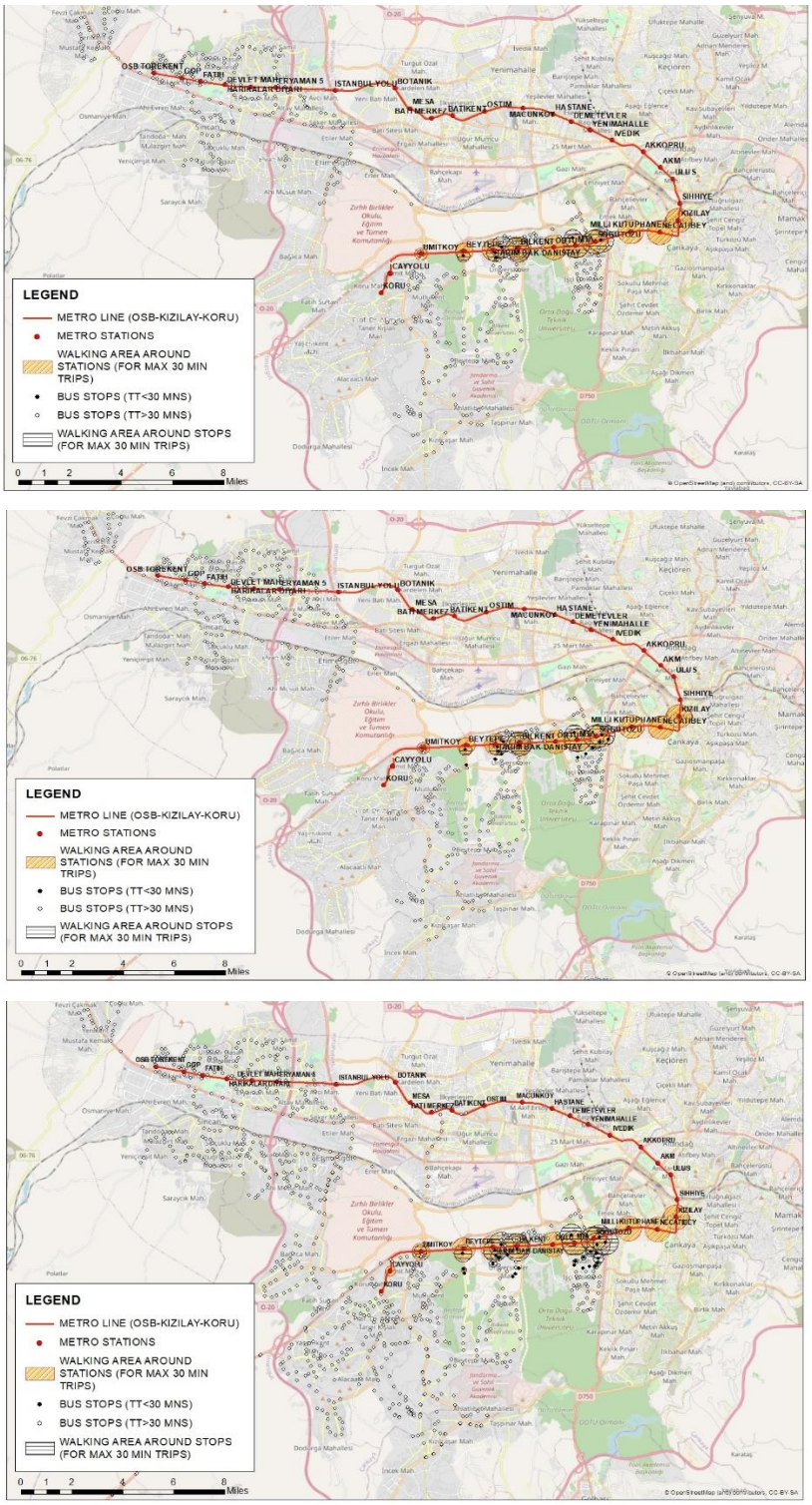


Figure 4.19 Areas Accessible from CBD in 30-Mins Travel Time in Off-Peak in Sunday (on the top), Off-Peak in Weekdays (in the middle), Peak in Weekdays (on the Bottom)

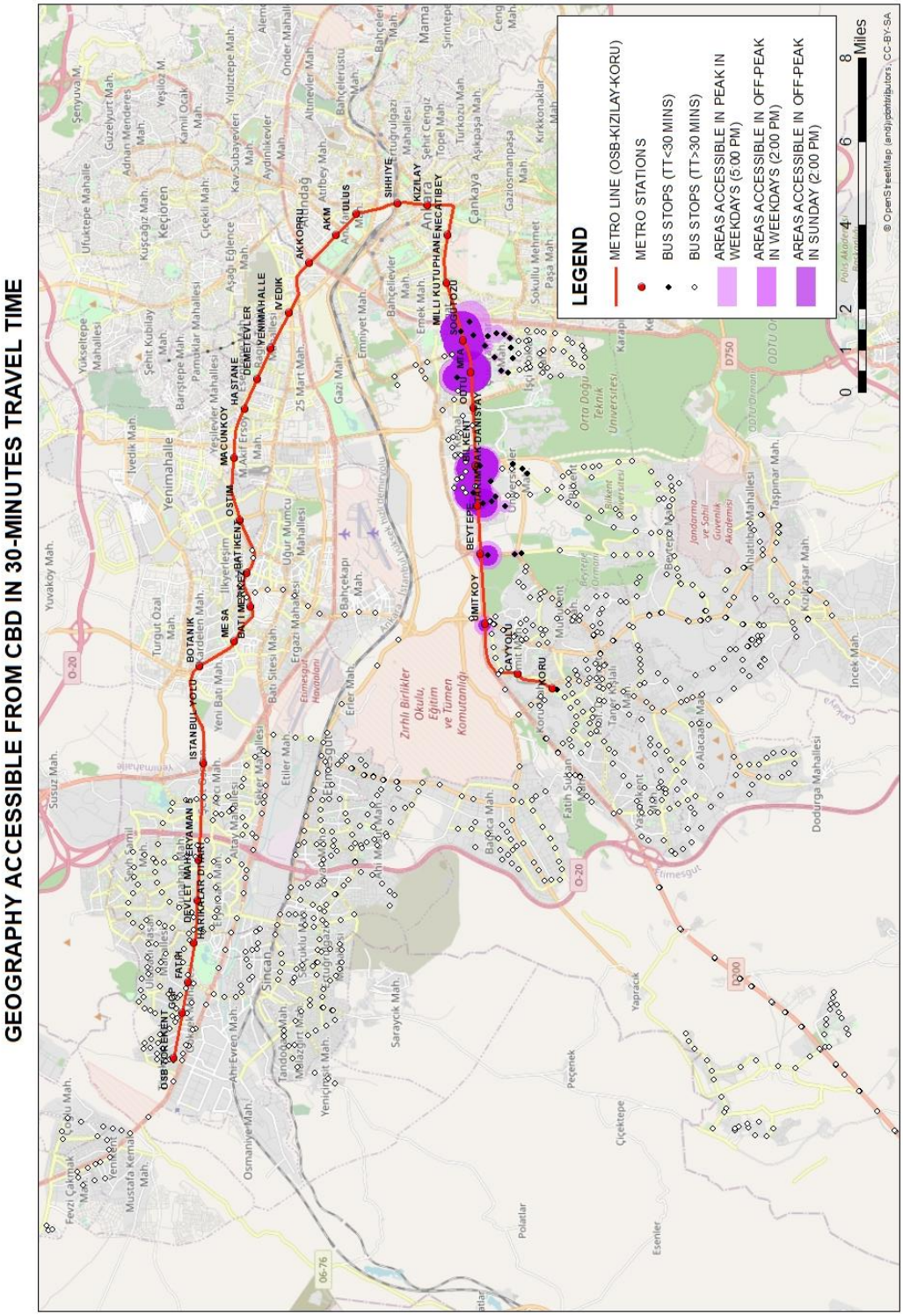


Figure 4.20 Geography Accessible from CBD in 30-Mins Constant Travel Time

The maps showing the area accessible from Kızılay station in a 30-minutes travel time budget through the metro line and integrated bus lines are available in Figure 4.19 and Figure 4.20 above.

Travel time cost for reaching Söğütözü station –the first station having bus connection- is 11 minutes on peak hours in weekdays (WK17) and 13 minutes on off-peak hours in weekdays (WK14) and off-peak hours in Sundays (WKN14). The arrival stops of the feeder bus lines which can be reached in the remaining 17 and 15 minutes (after 2-mins walking from station to the departer bus stop) from the 30-minutes travel time budget are more than those connected to other stations and also corresponds to a wider geography as seen on the map.

Moving towards the next station –the MTA- the travel time cost for reaching the arrival station increases only 2 minutes and becomes 15 minutes on WK17 and 17 minutes in WK14 and WKN14. But the area accessible through MTA station is not vidibly narrowed when compared to Söğütözü as the travel time cost is very litle under the same amount of travel time budget.

The accessible area around the ODTÜ (METU) station could not be evaluated because there was no feeder bus lines in service at the date of data collected. The trend of narrowing accessible area due to the budget constraint as moving towards the outer stations reveals itself at the Bilkent too. However, the station of Danıştay corresponding to the midpoint of the line provides an accessible area of almost the same size as Söğütözü and MTA stations although travel time costs for reaching there is 19 minutes in WK17 and 21 minutes in WK14 and WKN14. The increase in travel time cost for reaching to the station and the following decrease in remaining time for feeder bus travel does not appear to be reflected in the accessible area. Therefore, it is thought that waiting time for feeder busses or their average speed are not equal for these stations. The statistical analysis of the data stored in the matrix and the criteria such as average bus waiting times, travel times of the busses will be discussed and compared in detail in the next section. But it should be noted here that the Danıştay station is the one with the lowest average waiting time for the feeder

busses (4 mins in WK17 and WK14, 8 mins in WKN14). This is most probably because bus lines connected to Danıştay station have a higher service frequency than the others as it provides access to Bilkent City Hospital which is a very intensively used public area.

Coming to the Beytepe station, the access time increases to 21 minutes on WK17 and to 23 minutes in WK14 and WKN14. As a result, the area accessible in the remaining very little amount of time busget has significantly narrowed. The waiting time for the busses are much lower than the average in the remaining accessible stops since more than one lines passes through these stops.

The station of Ümitköy is accessed in 21 minutes in WK17 and 23 minutes in WK14 and WKN14 from Kızılay trhough metro travel. Remaining time budget does not allow to reach an arrival bus stops after waiting for the busses. However, there is an area which is accessible without transferring to bus but compensating the bus waiting time with walking as there are two arrival bus stops within a walking distance to Ümitköy Station. Since there is no transfer bus line integrated in Çayyolu station, it could not be included in the evaluation.

The distinction between the accessible areas in WK17, WK14, and WKN14 could also be observed on the map. Although the accessible areas in off-peak hours in weekdays or in Sundays (WK14-WKN14) does not constitute a significant spatial difference, a wider accessible area is observed at almost all stations on peak hours in weekdays (WK17). The stations where the difference between accessible areas on WK17 and WK14-WKN14 is bigger are The Söğütözü station and Danıştay station followingly. The obvious reason for such a difference in Söğütözü station is that the frequency of feeder busses in WK17 is significantly higher compared to other day and times. The time saving for bus waiting undoubtedly expanded the accessible geography. The area accessible through the Danıştay station in WK17 is also wider than those in other times and days as a result of shorter waiting time for metro service although the bus waiting times are equal. In other stations, small amount of differences in waiting times are not reflected in the accessible geography.

The geography constituted by the areas accessible within 30-minutes travel time from Kızılay by means of Kızılay-Koru metro line and feeder bus lines is very narrow. The eaclidean distance of the farthest point that can be reached through Söğütözü station –where the remaining time for transfer and bus travel is higher- is 2 km to the station, and decrase to 800 meters at Ümitköy station. Considering that this distance is gettin shorter as going towards the outer stations, it is concluded that only the areas less than 2 km away from the metro line are accessible. The Koru station, the last station on the line- is not allowed to be accessed within the 30-minutes travel time constraint.

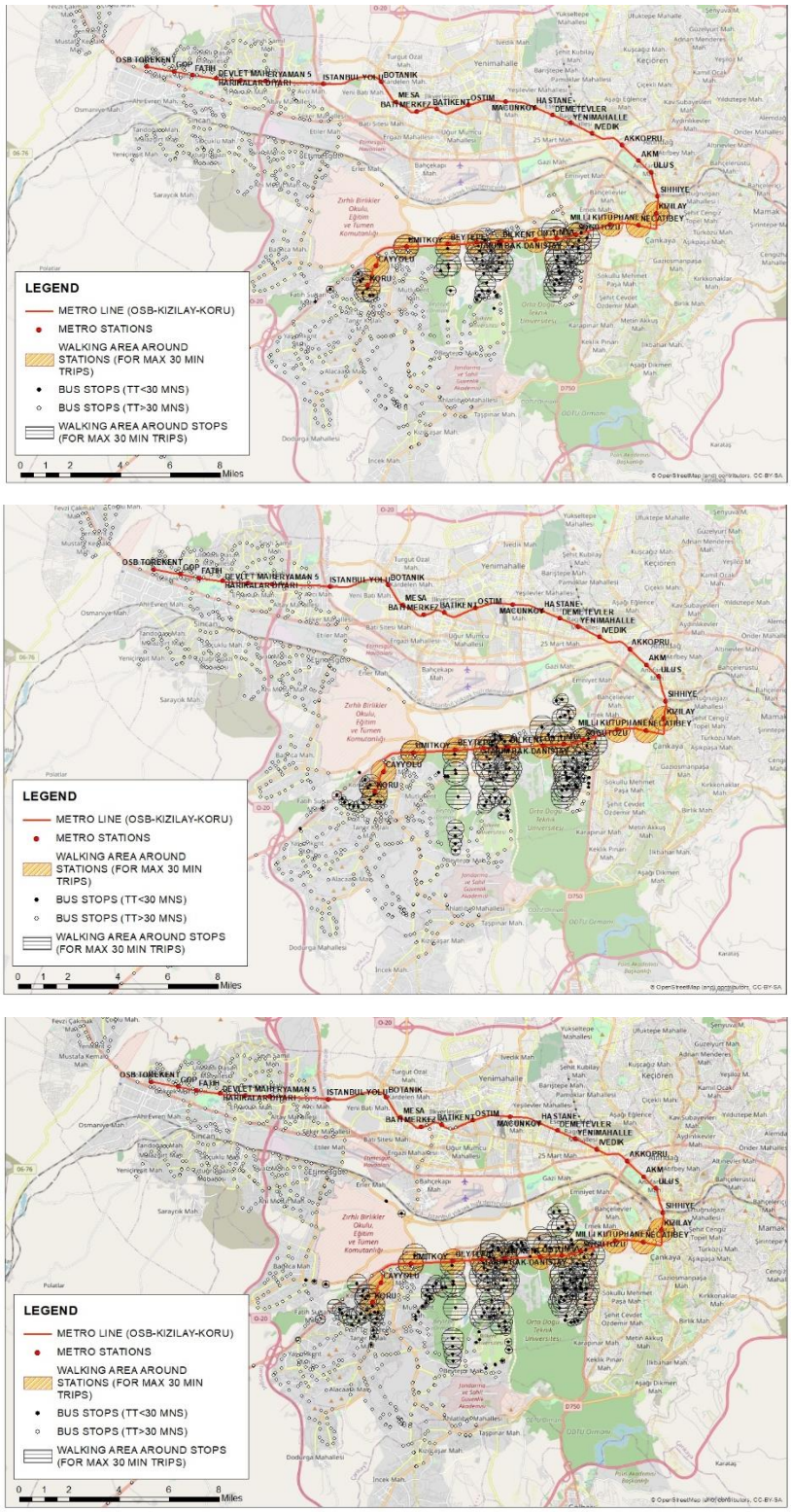


Figure 4.21 Areas Accessible from CBD in 45-Mins Travel Time in Off-Peak in Sunday (on the top), Off-Peak in Weekdays (in the middle), Peak in Weekdays (on the Bottom)

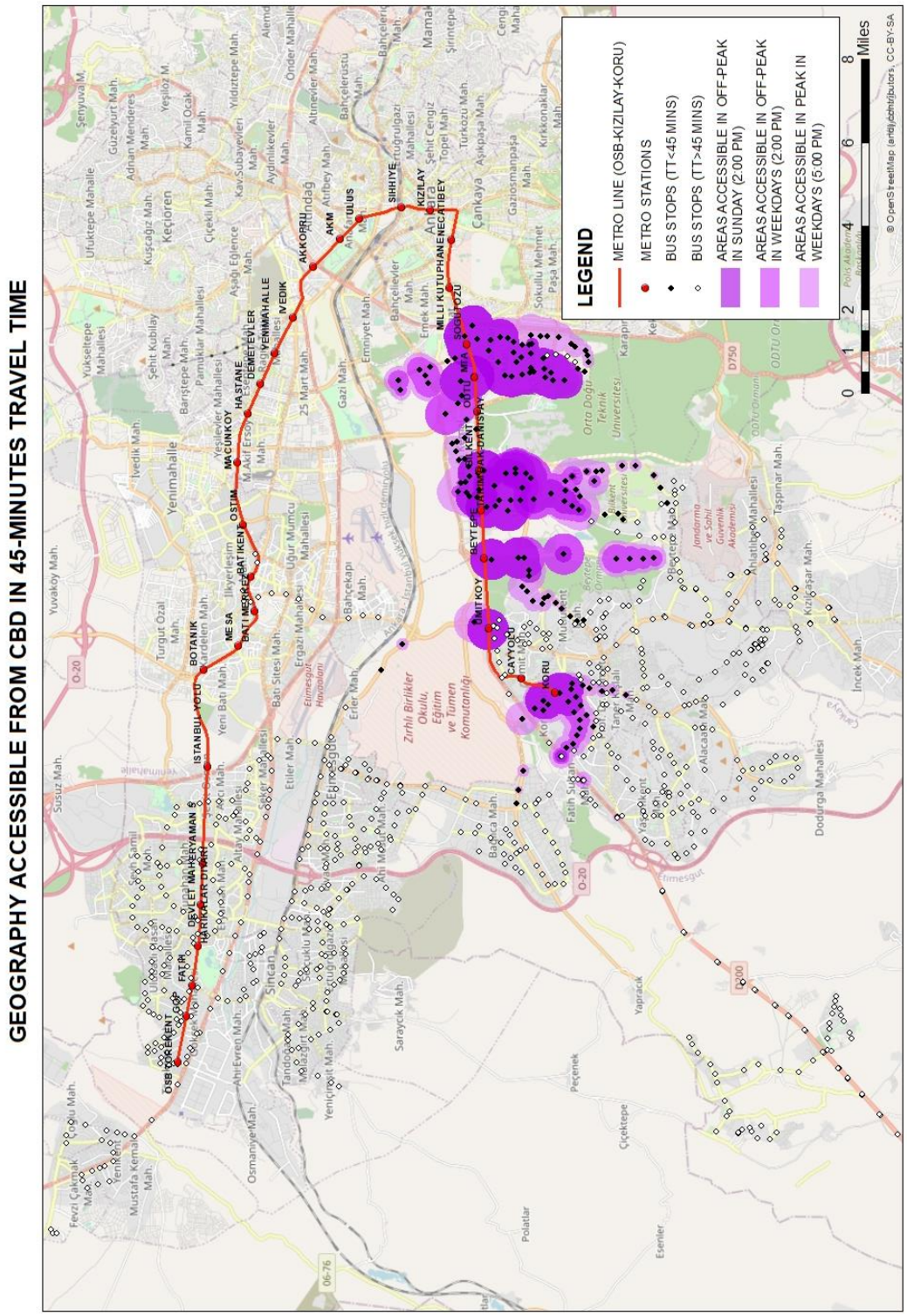


Figure 4.22 Geography Accessible from CBD in 45-Mins Constant Travel Time

The accessible geography in peak and off-peak hours in weekdays and off-peak hours in Sundays within the 45 minutes travel time budget assumption are presented in the maps in Figure 4.21 and Figure 4.22.

It is seen that accessible area is concentrated in certain corridors connected to the metro line . Travel time cost to reach the first bus-connected station in the metro line –Söğütözü Station- is 13 minutes in WK17 and 15 minutes in WK14 and WKN14. The time remaining from the budget allows to reach almost all the bus stops that feeder busses pass through. There are a few bus stops out of the accessible area not because they are located far from the station but since the access time to these stops are higher than 45 minutes due to the meandering bus lines. In addition, accessible areas in WK17, WK14 and WKN14 are almost the same around Söğütözü Station.

All the bus stops connected to MTA Station –the next station- are accessible in 45 minutes. The remarkable point is that almost no stop is accessible in Sundays while all of them are accessible within 45 minutes in weekdays. The reason is that the frequency of bus services in Sundays is halved (from 2 to 1) and the average bus waiting time is doubled (from 15 minutes to 30 minutes) as a result. The farthest feeder bus stop is only 3 km away from the MTA station but is limited by the time budget to be spread from by walking.

Travel time cost to reach Bilkent Station from Kızılay is 17 minutes in WK17 and 19 minutes in WK14 and WKN14. As the travel time budget of 45 minutes do not constitute a rigid constraint for travels to the initial stations and to arrival bus stops from stations, the trend of narrowing accessible geography as going beyond on the line is not yet observed. Although not oll the arrival bus stops connected to Bilkent Station are not accessible within 45 minutes, it provides an accessible area broader than thet of Söğütözü Station. The primary reason is that the stops of feeder bus lines connected to Bilkent station are more and spreaded around a wider area. The accessible area in WK17 differs significantly from that in WK14 and WKN14 at Bilkent station as expected. It is because the bus service frequency decreases in

WK14 and halves in WKN14 even though the service lines and the physical infrastructure do not change.

Accessible area around Danıştay station covers all the connected bus lines around although it is the next stop and expected to have narrower accessible area. However, no visible difference is noted in terms of accessible areas in weekdays and Sundays. The reason for this is that the area connected via Danıştay station is limited to the city hospital and the transfer bus frequency is much more than other stations.

Considering the accessible bus stops connected to Beytepe Station, it is possible to assert that the farther distances to the station than that in Söğütözü station are now accessible. However, it is seen that the accessible area has started to get narrow due to the time constraint when the walking buffer areas are regarded. Although this is thought to be due to shorter waiting time, statistics given in the next part do not affirm such a difference in waiting times. Another point on the map is that a prominent bus line from the Beytepe metro station to the south goes directly without being entangled in the neighborhood, as a result of which it provides access to a farther point. Nevertheless, many bus stops that have connection to Beytepe station are still unaccessible within 45 minutes. In addition, accessible area around Beytepe station in weekdays and in Sundays are significanlty different from each others since the headway of bus services rises more than double (from 8,7 minutes in WK17 and 12,7 in WK14 to 20 in WKN14) in Sundays.

The feeder busses that have stops in Etimesgut and Sincan in the northern settlement area are connected to the line via Ümitköy Station. However, there is a very limited area is accessible by the feeder busses within the remaining time from 45 minutes budget after travel time costs for accessing Ümitköy station -23 minutes in WK17 and 25 minutes in WK14 and WKN14- as seen on the map. The initial stops of the bus lines to the northern settlement area are accesssible in addition to the two stops nearest to the station. Still, the walking area around the few accessible stations are very limited by the time budget. The ratio of the numbers of accessible stops

connected to Ümitköy station is only 1% under 45 minutes travel time budget in WK17, WK14, and WKN14, which will be explained in detail in the next section.

Coming to the Koru –the last station on the line- accessible area within 45 minutes travel time budget has got narrower than those in other stations. Although there are high number of feeder lines, only a few initial stops on these lines are accessible in the remaning time from 45 minutes after travel time cost of 29 minutes in WK17 and 31 minutes in WK14 and WKN14. The accessible areas in WK17 and WK14 slightly differs causing by a few minutes in waiting times both for metro and busses. The area accessible under the conditions of WKN14 –on the other hand- is visibly narrower than the others.

Consequently, it is clear that the overal accessible geography expands significantly when the travel time budget is assumed as 45 minutes. However, much less than half of the geography to which the physical infrastructure of integrated system of public transportation is still unaccessible within 45 minutes time budget. Considering the stops the travel time cost of accessing to which is higher than 45 minutes –shown in white dots in the map-, only 17% of total bus stops (163 out of 956) are integrated to the metro line so that it will be accessed within 45 minutes from Kızılay-the city center. Especially the northern settlement area that is integrated to Koru metro line through Ümitköy station is not available to be reached within the time budget by menas of feeder bus lines. The longest distance that can be accessed from Söğütözü –the first transfer station on the line- within 45 minutes total travel time by the feeder busses is 5 km, which has decreased to 3,5 km in Koru –the last station. Correspondingly, the total area of the geography accessible through Söğütözü station is 59 km^2 whereas it falls to 20 km^2 for Koru station within 45 minutes travel time budget.

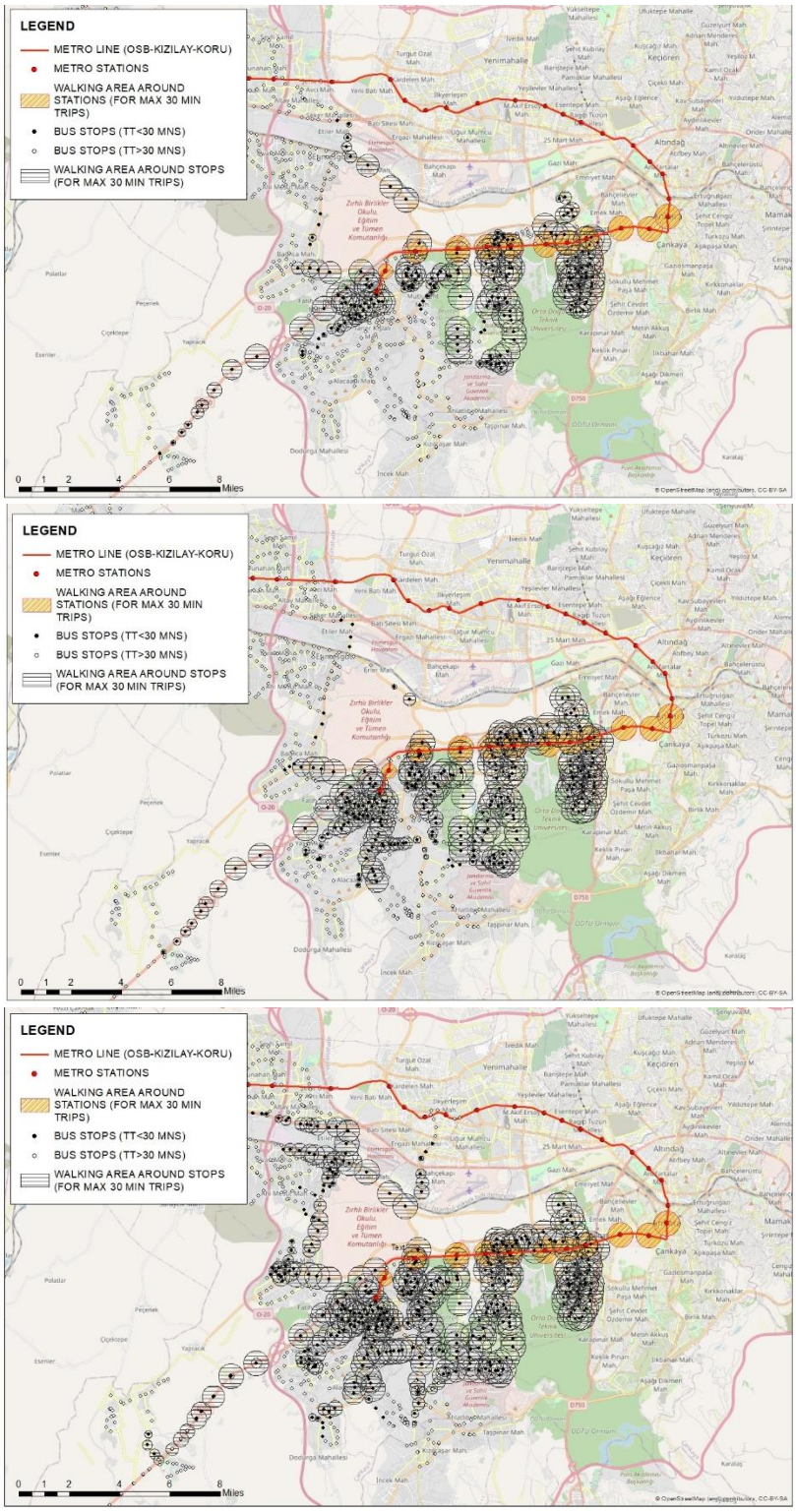


Figure 4.23 Areas Accessible from CBD in 60-Mins Travel Time in Off-Peak in Sunday (on the top), Off-Peak in Weekdays (in the middle), Peak in Weekdays (on the Bottom)

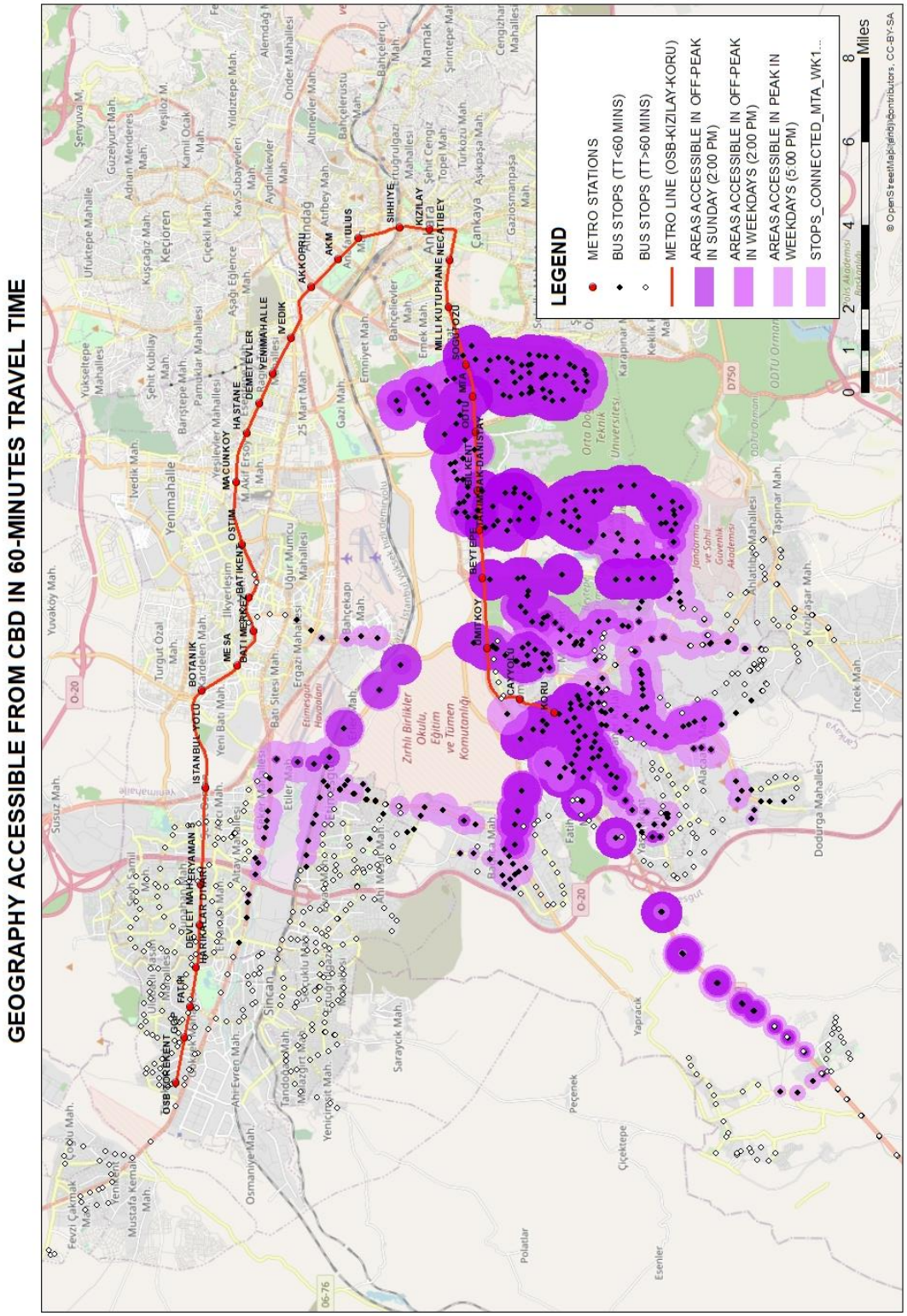


Figure 4.24 Geography Accessible from CBD in 60-Mins Constant Travel Time

The accessible geography within 60 minutes, the highest travel time budget assumption, in WK17, WK14, and WKN14 are shown in the maps in Figure 4.23 and Figure 4.24.

In Söğütözü, the differences in accessible geography in 60 minutes in terms of time of the day and days of the week have disappeared when compared to that in 45 minutes travel time budget while almost the same width area is accessible in the two. Namely, the corridor bordering the accessible geography from the east –which was accessibly only at WK17 in 45 minutes- becomes available both in WK17,WK14, and WKN14 within 60 minutes travel time. As the employed infrastructure is permanent, it must be caused by varying waiting times both for metro and busses at departing stops. The statistics explained in the next section reveal that average waiting time for the feeder busses at departing stops is 6,8 minutes in WK17 which rises to 10 minutes in WK14 and to 15 minutes in WKN14 whereas metro waits 2 minutes more in WK14 and WKN14 than in WK17. The time spent in the waiting activity seems to be resulted in narrowing accessible geography. Additionally, all the bus stops that have connection to Söğütözü station are accessible within 60 minutes travel in both WK17, WK14, and WKN14. The walkable areas around these stops on the other hand covers the entire settlement area which is expected to be serviced by Söğütözü station. The bus lines meander within the neighborhoods because of the areal spatial structure of the settlement, which led to walkable areas around stops to highly overlap.

Similarly, all the bus stops are within the accessible area in 60 minutes around MTA station, as well as in 45 minutes time budget. But, the walkable area has expanded especially for WK17 even at the last station. Furthermore, the last few stops on the bus lines that are not accessible in 45 minutes became available in 60 minutes. There is no time limitation to walkable area in WK14 and WKN14 after having accessed to the last arrival stop which is only 3 km away from the MTA station. However, the walkable area from the last stop is constrained by the remaining time as only 400 m radius around it. Indisputably, this is due to the much more lower frequency of bus services at the weekend (2 per hour in weekdays, 1 per hour in Sundays).

Regarding the area accessible via Bilkent station, it seems to be expanded comparing to the earlier stations on the map in Figure 4.24, which may mislead the research. It is because whether the accessible area around a station is bigger or smaller than the others is based on especially the sizes of Söğütözü accessible area, which is located very near to the station and in an areal form but not a long corrider, etc. Therefore, the bus lines and stops are scattered throughtout the area and the border of the accessible area is relatively close to the station. Yet the bus lines departing from Bilkent station deliver in a relatively long corridor since both the university area and the residential area served by Bilkent station are spread further forward. Consequently, there are bus stops at more distant point comparing to Söğütözü and MTA stations. The accessible areas around Bilkent station at WK17, WK14 and WKN14 under a 60 minutes travel time budget are considerably larger. The most of the existing stops that have connection to Bilkent station are within the accessible geography (70%) whereas a few of them (30%) are not accessible even within 60 minutes travel time budget.

The station of Danıştay serves for a small-size area through feeder bus lines all the stops of which are accessible within 60 minutes travel time in both WK17, WK14 and WKN14, similar to MTA. Moreover, even the farthest stop is accessed in total travel costs of 27-31-33 minutes from Kızılay. That is, there is no time limitation for walking from arrival bus stops to final destinations. There are two remarkable facts one of which is the shorthest average bus waiting time along the line is observed in transfer busses connected to the station of Danıştay. The second on the other hand is that all the stops are accessible not only because they have already scattered along a very small area which is located very near to the station but also due to short waiting time for transfer busses.

When the accessible area connected to Beytepe station is evaluated, it can be said that it goes further than the accessible area around the Söğütözü station and reaches almost the same distance as the accessible areas around the Bilkent station. It was previously stated that the accessible area connected to Söğütözü station is not restricted by the time budget but by the size and areal form of the settlement area

serviced. Comparing the Bilkent and Beytepe stations, the average bus waiting times in transfers from Bilkent are 12-16-25 minutes while those from Beytepe are 8,7-12,7-20 minutes in WK17, WK14, and WKN14 in sequence. As a few minutes of negative difference in travel time costs of accessing the stations is compensated by the positive difference in bus waitin times, the accessible areas reaches almost the same distances. But the accessible area around Bilkent station is much more wider (123 km^2 in Bilkent/56 km^2 in Beytepe in WK17) when the overall geography consituted by the accessible areas around each accessible stops are compared instead of the maximum distance that can be accessed. It is clear that the reason is not time budget limitation as the travel time costs for accessing to the station are almost the same for the both. The reason is that existing bus stops connected to Bilkent station spread over a much wider area while those connected to Beytepe station are spread over a limited area similar to MTA, Danıştay, and Söğütözü stations. It is an inevitable consequence of infrastructure provision pattern. The difference in total travel time costs of getting a feeder bus at a departing stop is almost negligible between the two stations. In addition, most of the arrival bus stops from Beytepe station (80%) are within the area accessible under 60 minutes travel time budget assumption.

The bus lines departing from Ümitköy station mostly serve for the northern settlement areas as feeders for metro line. The accessible geography at north –which could not be identified before because of travel time limitation- becomes evident on the map showing accessible geography in a 60 minutes travel time. The settlements at the north of Ümitköy station are not near to the line as those in the south. On the contrary, the settlement areas start at a certain distance to Ümitköy station, as a result of which the busses do not face with urban traffic jams and do proceed into the settlement areas almost expressly. Similarly, the bus route towards to the west along Eskişehir road is express and has created an accessible area that visibly spread further than the accessible areas around other stations. But, all the arrival bus stops at the south are within the accessible area while a large number of those at the north are not accessible even within the largest travel time budget of 60 minutes. As for the

accessible areas observed on different days and different times, almost equally accessible area is provided by the conditions of WK14, WKN14 while a wider area is accessible within the given travel time budgets in WK17.

Coming to Koru station, it seems that the accessible area gets narrower from the station towards the northern and southern settlment areas compared to other stations.The bus lines from Koru to the west along Eskişehir road provides accessibility to the further areas than those from Ümitköy does. The bus stops on this line which are within the accessible area but also shown in white are not those departing from Koru station but from Ümitköy Station that are not accessible in 60 minutes. Although there is a large accessible area around Koru, not all the existing bus stops are covered (only 36% in WK17) since the time constraint gets through the accessible area.

There is almost no time limitation on accessible geography around Söğütözü, MTA, Bilkent, Danıştay, and even Beytepe stations –which are the inital station that have bus connections on Koru direction- in a quite high budget of 60 minutes. However, it is also observed that even a 60 minutes travel time budget constitutes a time constraint and do not allow to access to more than half of the arrival bus stops located in a very large area around Ümitköy and Koru stations –the two major transfer stations within residential areas-. On the contrary, almost all the bus stops connected to initial stations are within the accessible area as there is no effect of time budget limitation. Therefore, the hypothesis that the area accessible around the stations by feeder busses narrows as the remaning time for bus travel decreases as the access time to the station increase as going outer from the central stations has not clearly shown itself in the geography map under 60 minutes time budget assumption. Yet the time constraint is evidently effective when accessible area connected to Ümitköy and Koru stations are preciesly compared –where 78%-64% of the existing arrival bus stops are unaccessible in 60 minutes travel time budget. The farhest location that can be accessible in 60 minutes from Söğütözü station is approximately at 5 km distance –also the farthest stop- while it is about 10 km from Bilkent and Beytepe stations. Coming to the Koru station –the last one- the farhest distance to be reached

is 8 km within the settlement area when the western route as an express line is not regarded.

4.4.1.1.2 Accessible Geography in Fixed Days and Times of the Week

In the maps so far, how the accessible area is shaped and differs in days and times of the week under the fixed travel time budget assumptions has been explored. In the next part on the other hand how the accessible area is formed and changed under varying travel time budgets at a fixed days and times will be examined.

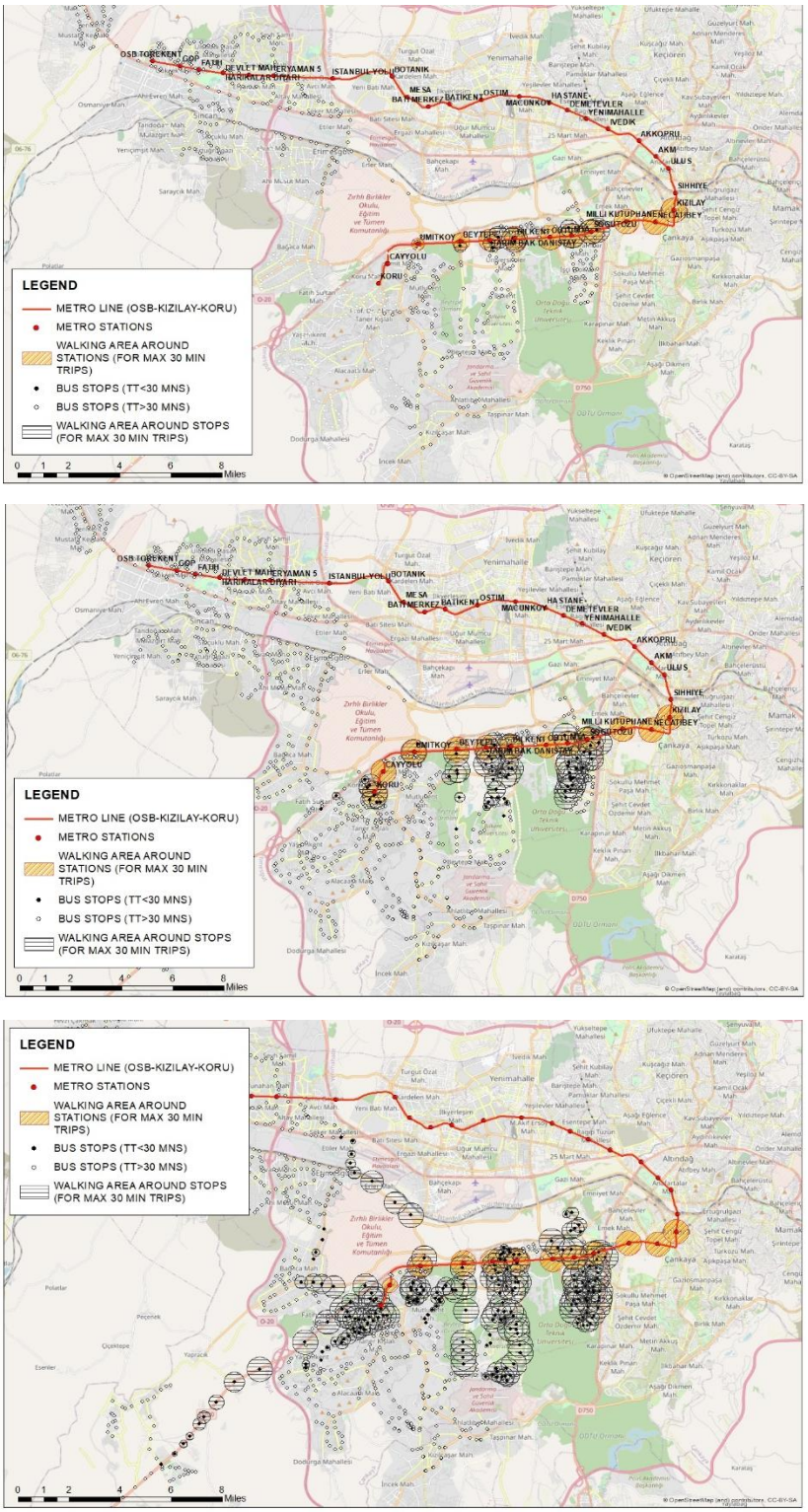


Figure 4.25 Areas Accessible from CBD in Off-Peak in Sunday in 30-Mins (on the top), 45-Mins (in the middle), 60-Mins (on the Bottom) Constant Travel Time

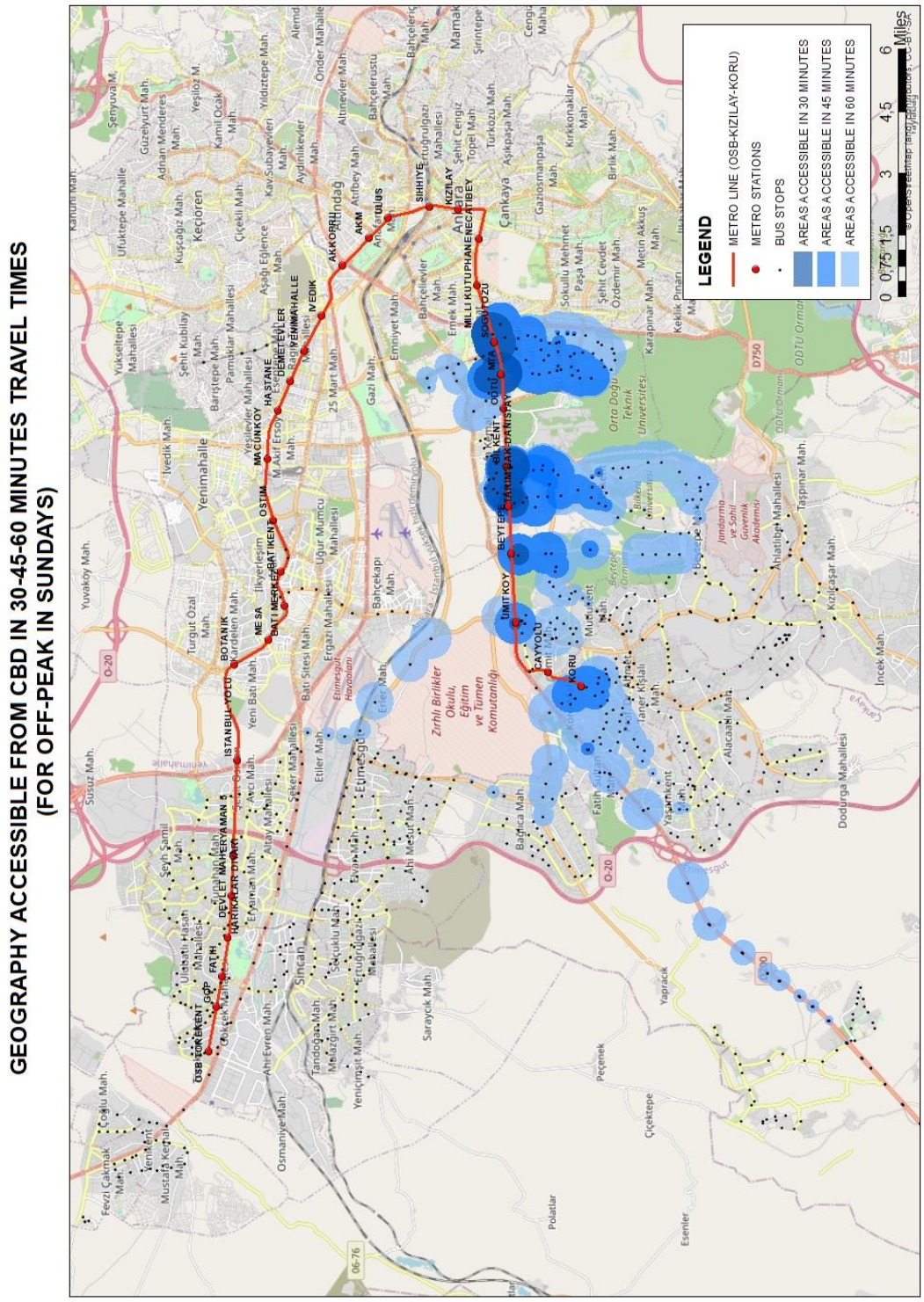


Figure 4.26 Geography Accessible from CBD in 30-45-60-Mins Constant Travel Times in Off-Peak in Sundays

The above maps in Figure 4.25 and Figure 4.26 show accessible area patterns linked to all stations at off-peak hour (2.00 pm) on Sundays. Travel time cost for reaching the Söğütözü station from Kızılay is 13 minutes in off-peak hour in Sundays (WKN14). There are only two stops that can be accessed in the 30 minutes time budget including egress and bus waiting time costs. When the budget is assumed as 45 minutes, all the stops except the ones on line constituting the eastern boundary of serviced settlement are within the accessible area even in an off-peak hour. Under the assumption of 60 minutes travel time budget all the stops that have bus connection to Söğütözü station are accessible. Considering that there is a single bus line (136) connected to Söğütözü station on Sundays which starts from the north part of serviced neighborhood an reaches the south along the western boundary, it is concluded that the time constraint manifests itself as getting from northwest to southeast. The eastern corridor within the Söğütözü station service area where the access is limited also becomes accessible in 60 minutes travel time. The farthest locations that can be accessed in a total travel times of 30-45-60 minutes are in sequence at 1 km-4,5 km-5 km distances from the station. The accessible geography constructed by the walking buffers around each accesssible stops covers a 4 km2 when travel time budget is 30 minutes and expans to a 40 km2 in 45 minutes and to 72 km2 in 60 minutes travel time budgets.

There is a single feeder bus line from MTA station the travel time cost to access which is 15 minutes in WKN14. All the connected bus stops are accessible within 60 minutes while only the first a few stops are in the geography accessible in 30 and 45 minutes travel time budgets. The accessible area is available at most to 1 km distance from MTA station in 30 minutes travel time budget, to 1,3 km in 45 minutes and to 3,2 km in 60 minutes travel. It corresponds to a 3 km2 – 4 km2- 13 km2 in 30-45-60 minutes in sequence.

Bilkent station enables access for all the arrival bus stops at the north in 30 minutes travel time in WKN14 while no stop in the south is accessible through it. Increasing the travel time budget to 45 minutes, the accessible geography in the north only expands as a few hundred meters of walking area but a clear accessible geography is

formed in the direction of residential area in the south. Nevertheless, the time constraint has ended up this corridor of accessible aree before reaching the middle of the settlement area. The accessible area in the south direction is more than doubled when the travel time budget is assumed as 60 minutes. Still the 56% of the existing arrival bus stops connected to Bilkent station are not accessible even within a 60 minutes travel time. Although the accessible area in the norhern side has expanded to a few more stops, there are also stops in the northern neighborhood –which is located very near to the station- that can not be accessible within 60 minutes. The total area of accessible geography around Bilkent station rises from 5 km2 in 30 minutes travel time to 14 km2 in 45 minutes and to 51 km2 in 60 minutes.

The Danıştay station provides access for City Hospital campus area as mentioned before. Travel time cost of getting the station from Kızılay is 21 minutes. Considering that the average bus waiting time at transfer stop is 8 minutes, it is unsurprising that only one stop is accessible in 30 minutes of total travel time. The walking distance is contrained by the time budget although all the stops become accessible in 45 minutes. The limitation on walking area arond the arrival stops disappears when the time budget is assumed as 60 minutes. Consequently, the farhest location to be accessed in 30 minutes is at 850 meters distance to the station, which rises to 2,5 km in 45 minutes and to 2,8 km in 60 minutes, where the farhest stop is 2 km away from the station.

Travel cost for accessing to Beytepe station is 23 minutes in WKN14. The remaining time from 30 minutes time budget is not enough even for the bus waiting time for almost any journey. The accessible area in 45 minutes travel time budget has so slightly expanded that the distance at which the furthest accessible location is from the station rises to 3 km from 700 meters. It has almost doubled and reached a distance of 7 km –where the furhest stop is- when the travel time budget is 60 minutes. However, several stops within the serviced neighborhood are not accessible even within a 60 minutes travel time due to reamling bus routes where the farthest stop is accessible.

There is only one stops accessible from Ümitköy station within 30 minutes and 45 minutes travel times in WKN14. The accessible area expands to a small but densely populated area in terms of bus stops to the south while it spreads at a 9 km distance along a corridor to the north where a few stops are located if the travel time budget is assumed as 60 minutes. Nonetheless, large numbers of bus stops scattered along the northern settlement area are not covered by the accessible geography. It includes the locations at most 250m-800m-9km distance to the station in travel time busgets of 30-45-60 minutes in sequence.

Koru station is not within the accessible geography under 30 minutes travel time budget as the travel time cost of getting Koru by train is 31 minutes in WKN14. The accessible area in the south and north of Koru station is highly restricted by the budget constraints of 45 minutes and 60 minutes. It is possible to access up to 5,5 km to the north and 1,5 km to the south in the remaining time. However, the bus line which goes not in the urban roads within neighborhoods but an express road to the southwestern direction provides access for location at most 17 km distance from the station. But a hundreds of stops (87%) at the north and south of the station are not accessible even in a 60 minutes in WKN14.

The map in Figure 4.26 above shows that 30 minutes travel time budget in WKN14 does not even allow for reaching Koru –the last station on the line- from Kızılay and allows only to access the first a few stops around the accessible stations. These are not more distant than 900 meters to the transferred stations. The hyphotesis that accessible areas around the stations get narrower as going outer from the central stations is clearly confirmed under the 45 minutes travel time budget. That is, the effect of budget constraint on accessible geography is possible to be observed on the map since the 45 minutes travel time defines a certain amount of accessible areas around each stops. Accordingly, an area up to 4,5 km distance from Söğütözü –the first transfer station- is accessible where it falls to 4,2 km from Bilkent –the mid station- and to 1,2 from Koru –the last station on the line. The travel time costs for reaching the transfer stations from Kızılay by a metro travel is 13 minutes for Söğütözü, 19 minutes for Bilkent, and 31 minutes for Koru station. In addition to the

time spent on train journey, average bus waiting times at these stations have a role on accessible geography to narrow as going further. At the end, a high rate of the stops on feeder bus lines connected to stations after Beytepe –including the Ümitköy and Koru stations which are the major tranfer stations on the line- are still unaccessible even within a 60 minutes travel time.

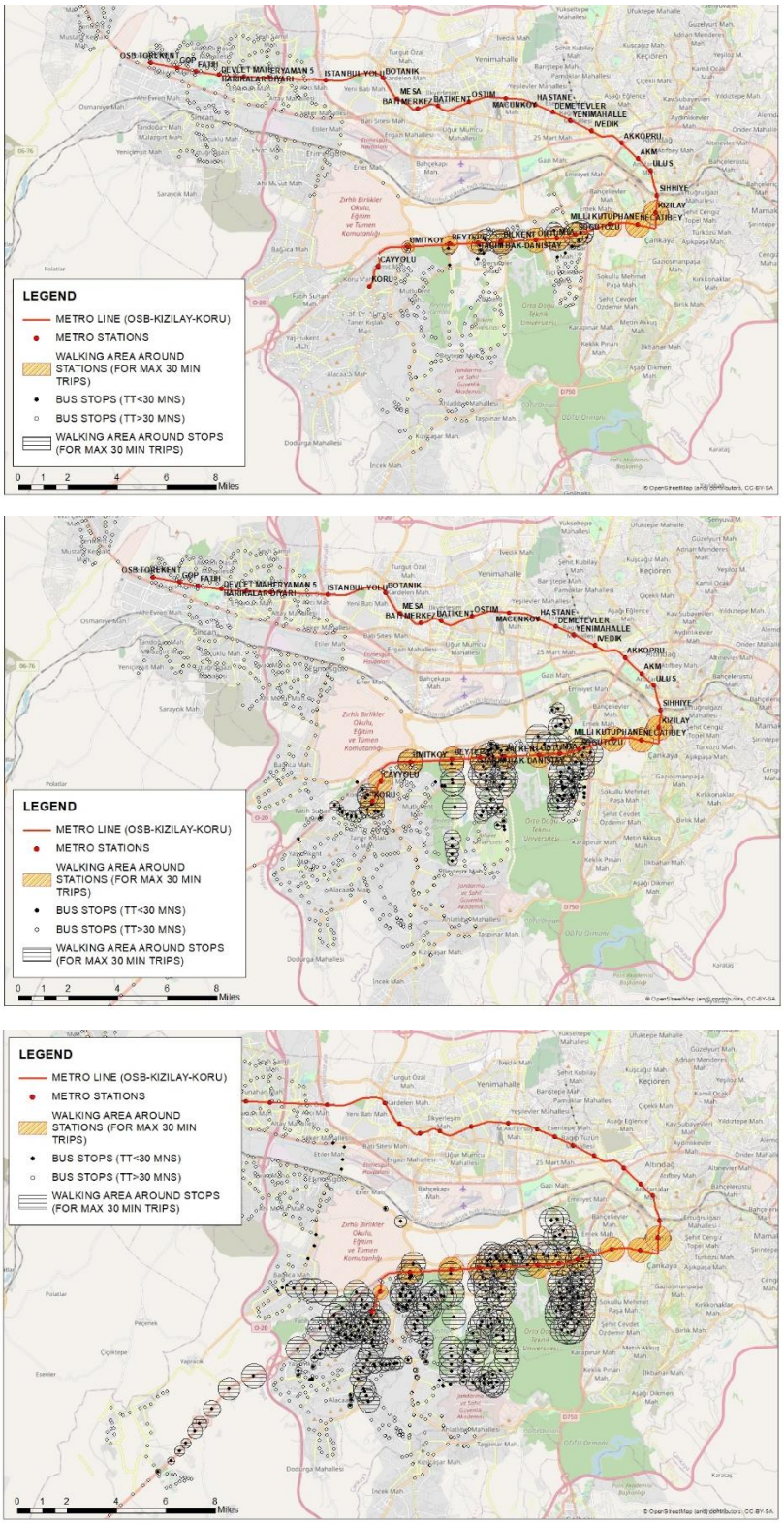


Figure 4.27 Areas Accessible from CBD in Off-Peak in Weekdays in 30-Mins (on the top), 45-Mins (in the middle), 60-Mins (on the Bottom) Constant Travel Time

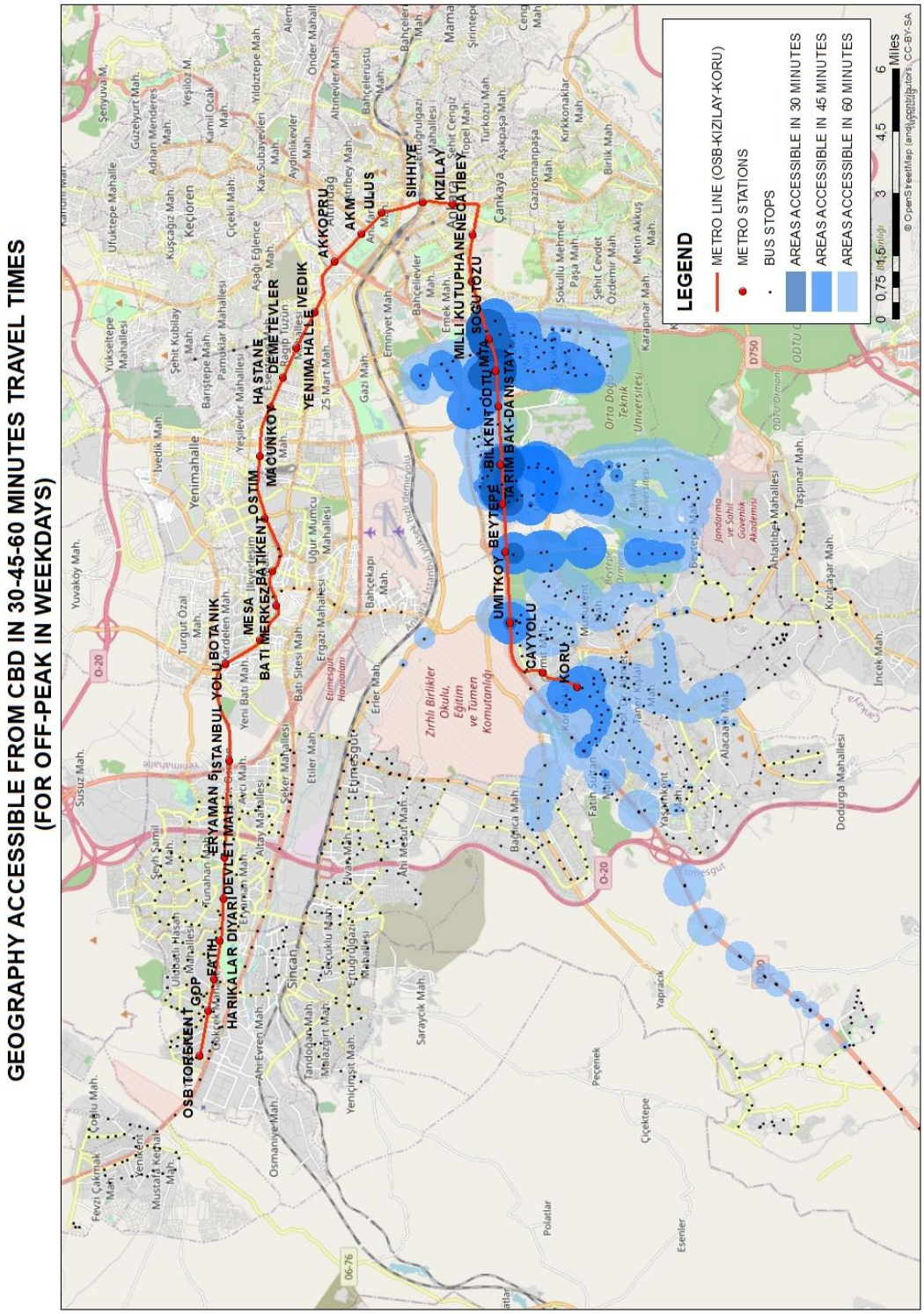


Figure 4.28 Geography Accessible from CBD in 30-45-60-Mins Constant Travel Times in Off-Peak in Weekdays

The maps in Figure 4.27 and Figure 4.28 show accessible areas linked to all stations at off-peak hours (2 pm) on weekdays, coded by WK14.

The accessible area that is created by the bus stops connected to Söğütözü station and walkin buffer around them in WK14 is exactly the same as it is in WKN14. The last few stops of the bus lines have a litle wider area of walking buffer due to the slightly lower bus waiting time in WK14 under 60 minutes travel time budget assumption. It takes 52 minutes of travel time to access to the furhest bus stops linked to the metro line through Söğütözü station. That is, a 60 minutes travel time budget prevents a maximum walking area around the last stops linked to Söğütözü station – the first transfer station. The travel time budget constrains the time available for the bus travel and hence the accessible area. So the areas of maximum 1 km-4,5 km-5,5 km distances to the station are accessible in WK14 under 30-45-60 minutes of travel time budget in sequence. The walking buffers around stops within these distances create an overall accessible geography of 5 km^2- 40 km^2- 86 km^2 in the given travel times.

All the stops linked to MTA station become accessible within 45 minutes travel time in WK14 while the accessible area is limited to only one stop in WKN14. Nevertheless, the time constraint is effective on walking distance around the accessible stops. Similarly, the accessible area covers all the stops the walking buffer around which have also expanded when the travelş time budget is assumed as 60 minutes. Accessible area limits reach up to 1 km in 30 minutes, 3,2 km in 45 minutes, and 3,6 km in 60 minutes of travel time budget. These distances includes overall accessible geography of 3 km^2- 13 km^2- 26 km^2 around MTA station in sequence.

The area that can be accessible through Bilkent station in 30 and 45 minutes travel time are almost the same. However, the area accessible in 60 minutes have expanded considerably both in the northern and southern settlement areas in WK14 when compared to WKN14. All the stops at the north are within the accessible area whereas almost half of the existing stops at the south are still unaccessible. The boundary of accessible area reaches to 1km-4,6km-8,5km under the travel time

budget assumptions of 30-45-60 minutes in sequence. It reaches farther from the accessible area around Söğütözü station although the travel time cost of accessing to Bilkent station from Kızılay is higher as it is further than Söğütözü station. On the contrary to the anticipation that the reason is shorther bus waiting time when transferring from Bilkent station to the busses, the average waiting time at Söğütözü is 10 minutes while that in Bilkent is 16.2 minutes which is much more longer. So the sifference between the sizes and spatial forms of the neighborhoods in which the Söğütözü and Bilkent feeder bus lines and stops are distributed as well as the varying bus speeds due to the road network and traffic characteristics of these regions could have effect on scope of the two accessible areas.

Travel time budgets of 45 and 60 minutes allows all the stops linked to Danıştay station to be accessed in WK14. Furthermore, the accessible area under 60 minutes travel time budget assumptions is the same as it is in WKN14. The walking buffer areas has expanded around a few stops as the remaining time for walking increases in 30 minutes and 45 minutes travel times when compared to those in WKN14. The furthest accessible locations are at 1 km-2,8 km-2,8 km distances from the station, the last connected stops to which is at only 2 km distance.

Coming to the accessible geography in WK14 created by the bus stops linked to Beytepe station, it is seen that the numbers of accessible bus stops in the south has increased and the accessible area has expanded when compared to those in WKN14 whereas there is still no stop accessible in the southwest part of the serviced neighborhood. There is also no reflection of time limit on the walking buffers around the stops in the south all of which has already been accessible in 60 minutes travel time. Travel time cost of getting the arrival bus stop named Faculty of Low is 41 minutes in total in WK14. But only the walkin time up to 10 minutes and the corresponding walking distance is included in the accessible geography since personal constraint of maximum walking time exists although the remaining time from the budget is 19 minutes. The accessible area has expanded considerably in the southwest direction comparing to that in WKN14. Yet there are many stops which are not accessible in a 60 minutes travel time. At the end, an area of maximum 850m

to the station in 30 minutes travel time, 7km distance in 45 minutes travel time, and 7,5km distance in 60 minutes travel time is accessible in WK14.

In contrast to all other stations, the accessible area around Ümitköy station observed in WK14 is narrower and reaches to a shorther distance than the accessible area recorded in WKN14. The maximum distances to the station that can be accessed in 30-45-60 minutes travel time budgets are 250m-800m-4,5km in WK14. Regarding the matrix showing the travel time distributions of each journeys, it is considered to be result of two factors: The first is that there are many stops that serviced by the transfer busses in WKN14 but not in WK14. In other words, some of the feeder lines do not stop at some stops on particular hours in weekdays while they stop at those stops at ceratin times. The second is that the service frequency of some particular lines is lower in WK14 than that in WKN14. So the bus waiting times for these lines are much more higher in WKN14 that it is doubled in some particular cases. At the end, the accessible geography around Ümitköy station in WK14 has significantly narrowed compared to WKN14 since some stops received no bus service and some are accessible in a longer time in WK14.

The Koru station is not accessible in a 30 minutes journey in WK14. The accessible area around Koru station in WK14 is available under a 45 minutes travel time budget assumption, which has expanded through a certain line in comparison to that in WKN14. The number of accessible stops within 60 minutes have increased especially to the south. The areas of which the furthest point is at 3,6 km in 45 minutes and at 6,5 km to the south and 17 km to the west in 60 minutes are accessible around Koru station. Still the most of the (77%) existing bus stops that have connected to the rail line through Koru station is not accessible even in a 60 minutes travel time in WK14.

Consequently, the travel time budget of 30 minutes does not even allow accessing from Kızılay to Koru –the last station on the line- and provides access to the first one or two bus stops from the accessible stations in WK14 as in WKN14. The 45 minutes travel time budget on the other hand provides accessible areas around Söğütözü,

MTA, Bilkent –the first transfer stations- which are at almost the equal sizes in terms of the maximum distance to the transferred station. Although the time budget allows to reach a little further distances via Söğütözü and MTA stations, the boundaries of accessible area around these stations are at almost the same distances to those of next stations as there are no further stops in the neighborhoods serviced by the bus lines departed from these stations. Accessible areas around Beytepe and Ümitköy stations under 45 minutes travel time budget are remarkable. Although the travel time cost for accessing Beytepe station is higher than the time spent to access the previous stations in total, there is an accessible area around Beytepe station that reaches further than the previous ones. The fact that the bus waiting time when transferring from Beytepe station is a few minutes shorther than that of Bilkent station may have caused an expansion in the accessible area by a few minutes of travel distance. It may also be contributed by variation in directness of bus routes. The effect of the travel time budget and travel time cost on the accessible geography is clearer under 60 minutes of time budget in WK14 rather than station-based special factors. The farthest point accessible in Söğütözü is at 5,5 km to the station the reason of which is not the time constraint but the form and size of the serviced settlement area. The accessible area extends to a distance of 8,5 km to Bilkent station, 7,5 km in Beytepe station and 6,5 km to Koru –the last station of the line. At the end, 685 bus stops out of those the infrastructure of which is provided are still out of reach in a high travel time budget of 60 minutes in off-peak hours in weekdays, which corresponds to 72%.

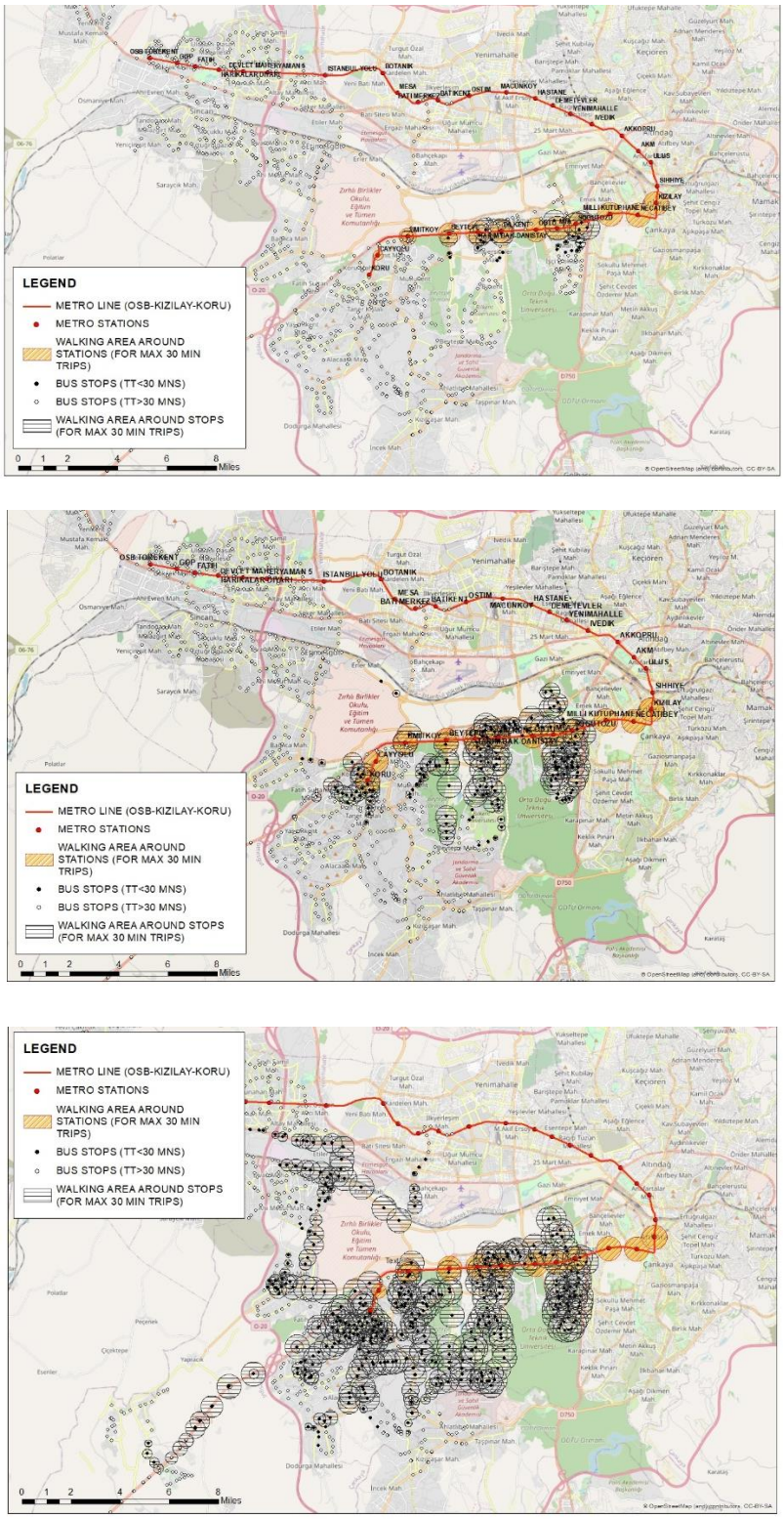


Figure 4.29 Areas Accessible from CBD in Peak in Weekdays in 30-Mins (on the top), 45-Mins (in the middle), 60-Mins (on the Bottom) Constant Travel Time

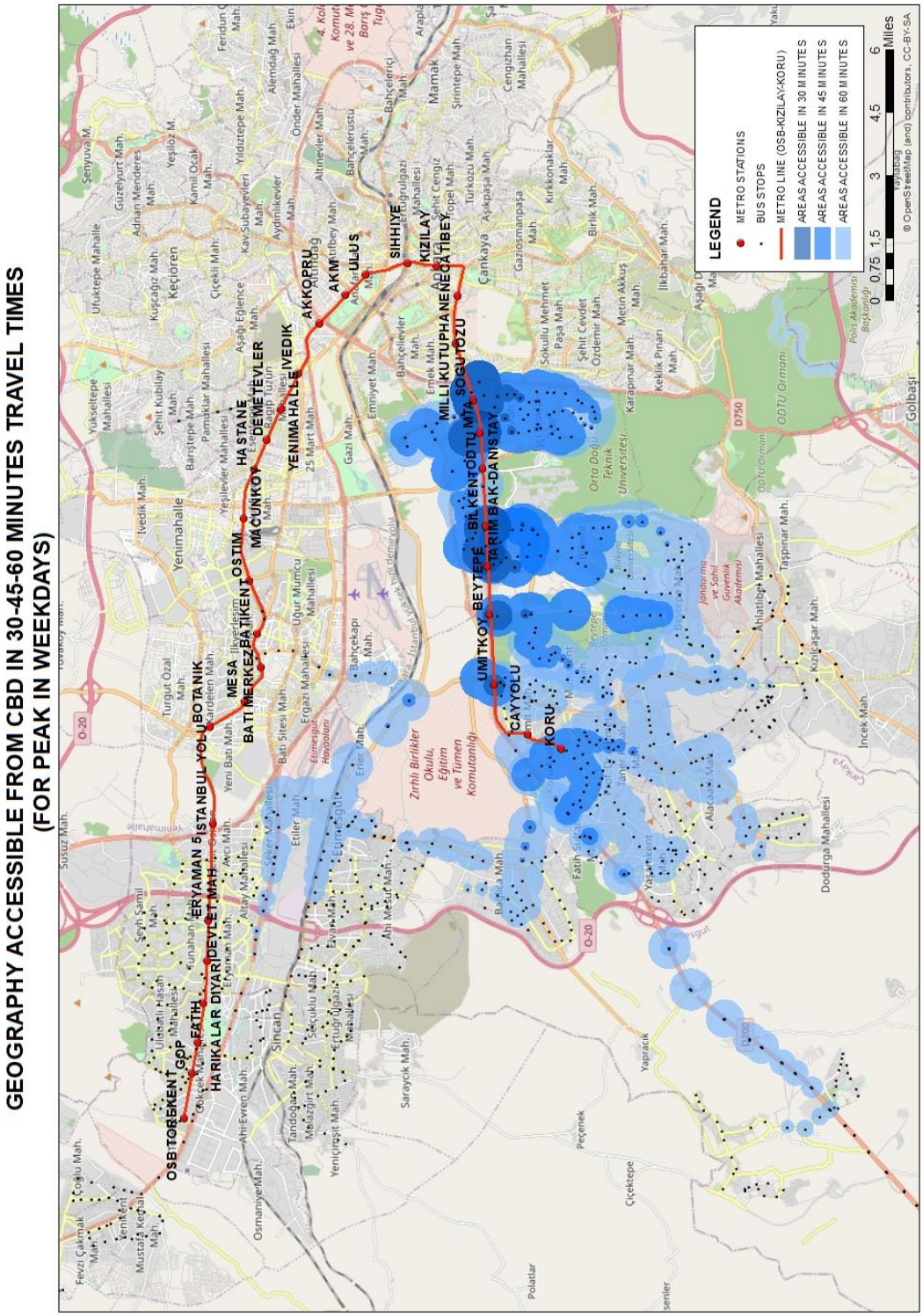


Figure 4.30 Geography Accessible from CBD in 30-45-60-Mins Constant Travel Times in Peak in Weekdays

The accessible areas around the stations under the travel time budgets of 30-45-60 minutes are explored in peak hours in weekdays (WK17) in Figure 4.29 and Figure 4.30.

The numbers of bus stops included in the accessible area around Söğütözü station has increased in 30 minutes and 45 minutes travel times in WK17 when compared to WK14 and WKN14. The average bus waiting time when transferring from metro to bus is 6,8 minutes in WK17 while it is 10 minutes in WK14. The time saved by bus waiting at exchange stops and train waiting at Kızılay station made it possible to access a few more arrival stops in the given time budgets. It is possible to reach 2 km distance from the station in 30 minutes and 5 km distance in 45 minutes travel time. The accessible area within 60 minutes remained the same as it is in WK14 because it is already possible to access the last stop and to the maximum walking distance from there without any time constraint. There is no additional accessible area as a result of the time saved. The furthest location to be accessed via Söğütözü station is at 5,5 km distance to it.

The average waiting times for the transfer busses from MTA station in WK14 and WK17 are equal but the accessible areas in 30-45-60 minutes have expanded approximately by 200 meters when compared to WK14 and become 1,2km-3,4km-3,8km in WK17. The only reason for this is the waiting time for train which is 2 minutes shorther in WK17. But the size and spatial form of the service area of MTA station is also effective in shaping the accessible geography in addition to the time budget constraint since the connected bus stops are spread over a limited area.

The accessible area around Bilkent station is also expanded as a result of fall in the average bus waiting time when transferring from train to 12 minutes in WK17 which is 16 minutes in WK14. Thus the accessible area limits have reached 2km-7km-10,8km distances to the station under the travel time budget assumptions of 30-45-60 minutes in WK17. Despite a high rate (71%) of the existing bus stops linked to the metro line through Bilkent station are within the accessible area in 60 minutes in

WK17, there are also unaccessible stops especially in Ahlatlıbel and Kızılcaşar neigborhoods.

Similar to Söğütözü and MTA stations, an extension of approximately 200 meters has been observed in the accessible area around Danıştay station in 30 minutes and 45 minutes travel times in WK17 comparing to WK14, which results from the decrease in train waiting time. Travel time budget of 60 minutes on the other hand does not cause a change in the accessible area in WK17 because there is no time limitation to reach any stops in 60 minutes.

Similarly, there is an increase in the number of accessible stops and the maximum distance to which the accessible area around Beytepe station reaches within 30 and 45 minutes in WK17. However, the extension is greater when the travel time budget is assumed as 60 minutes in which all the linked stops except for the two are covered by the accessible area. The accessible area in this case reaches 1,8km-7km-7,4km distances to the station under 30-45-60 minutes of travel time budget assumptions. However, it is necessary to make comparisons and evaluations based on the size of accessible area but not the maximum distance to be accessed as the accessible area has expanded to the southwest instead of towards the furthest location. So an area of 1 km2 is accessible where 8% of the total bus stops are covered in 30 minutes travel time. It expands to an area of 18 km2 including 54% of the stops in 45 minutes and to 56 km2 covering 79% of the stops in 60 minutes travel time.

The area accessible through Ümitköy station is the one which most differs in WKN14, WK14, and WK17. Although it has expanded only a few hundred meters within 30 and 45 minutes, a maximum distance of 4,5 km in 60 minutes travel time WK14 is accessible which rises to 4 km to the south, 4,5 km to the north, and 14 km to the west in WK17. Although it is clear that such a difference among the accessible areas in WK14 and WK17 is resulted by decreasing headway and thus decreasing bus waiting time in WK17, it is also because there are many stops which do not provided bus services in WK14 but actively serviced in WK17 as explained earlier. Finally, some of the arrival stops within the southern settlement area and the most of

those within the northern settlement area are still unaccessible even in a 60 minutes of travel time. The rate of stops within the accessible area in 60 minutes travel time in WK17 to the total number of existing stops linked to the metro line through Ümitköy station is 22%, which is 1% in 45 minutes and 0% in 30 minutes of travel time budget in WK17.

Coming to the Koru station, the station itself is accessible by a train travel from Kızılay in 29 minutes in WK17 the remaining from 30 minutes budget of which does not even allow for egress from the station. The accessible area in 45 minutes travel time are limited along certain bus lines and reaches to maximum distance of 5,5 km from the station. It significantly expands when the travel time budget is assumed as 60 minutes and creates an area reaching to 5,5 km distance to the northwest, 9 km distance to the south in the remaining time. However, the bus line which goes not on the urban roads within the neighborhoods but an express road to the southwest provides access for locations at most 17 km distance from the station. Yet the 64% of the existing arrival bus stop linked to Koru station are not covered by the accessible area in 60 minutes travel time in WK17.

The map in Figure 4.30 illustrating the accessibility under travel time costs of 30-45-60 minutes at peak hours in weekdays reveals that only small size areas are accessible around the initial transfer stations on the line as considerable amounts of 30 minutes travel time budget is spent on waiting for metro and train journeys from Kızılay to the arrival stations. As it is the case for other days and times, the accessible geography has expanded when the travel time budget is assumed as 45 minutes in WK17. However, more than half of the total number of bus stops connected to stations except Söğütözü, MTA, Danıştay stations are accessible neither in 30-45 minutes nor in 60 minutes of travel time. The travel time costs of accessing these stations is lower and the remaining time for accessing the arrival stops by bus travel is higher since they are the initial transfer stations on the line. In addition, the settlement areas in which the bus stops connected to these stations are spread over are smaller than the others. Therefore, the number of arrival bus stops connected to these stations is less and are more likely to be within the accessible area than those

connected to other stations. So the size and spatial form of the serviced area around stations is also effective in shaping the accessible geography in addition to the time budget constraint. There is no additional accessible area as a result of the time saved at these station because the time budget already allows to reach the last stops.

At the end, the farthest point accessible in Söğütözü is at 5,5 km to the station the reason of which is not the time constraint but the form and size of the serviced settlement area. The accessible area extends to a distance of 10,8 km to Bilkent station, 7,4 km in Beytepe station and 9 km to Koru –the last station of the line. At the end, 564 bus stops out of 956 –which are existing- are still out of reach in a high travel time budget of 60 minutes in peak hours in weekdays, which corresponds to 59%.

4.4.1.2 Statistical Measures of Accessible Geography

The spatial form of the accessible geography in the given travel time budgets and its alteration in peak and off-peak hours is described in terms of two measures: The first is the maximum distance that can be accessed from a station whereas the second is the total area in kilometer square that the walking buffers around all the stops linked to each stations creates.

Theoretically, the longer the travel distance, the longer the travel time and the shorter the remaining time for the next segment of the trip, as a result of which the maximum distance that can be travelled in the latter segment of a trip in a multimodal integrated system decreases. Accordingly, the closer the arrival station to Kızılay, the shorther the in-train travel time and the longer the time budget remaining for the next section –which is the bus travel- which expected to be resulted in a longer distance that can be travelled by feeder busses. But the time costs of egress from the station and waiting for the transfer busses are also parts of the total time cost of a travel. Therefore, the effect of waiting times and in-vehicle travel times on shaping the

accessible geography is evaluated through comparing the eaclidean distances and the total area of accessible geography around each stations.

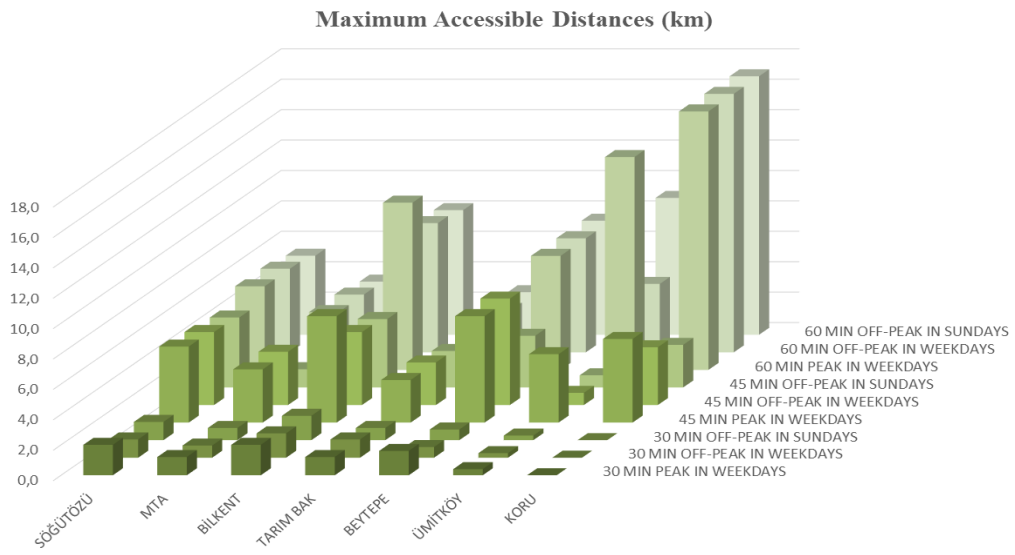


Figure 4.31 Distances Accessible in Constant Travel Times From Each Station

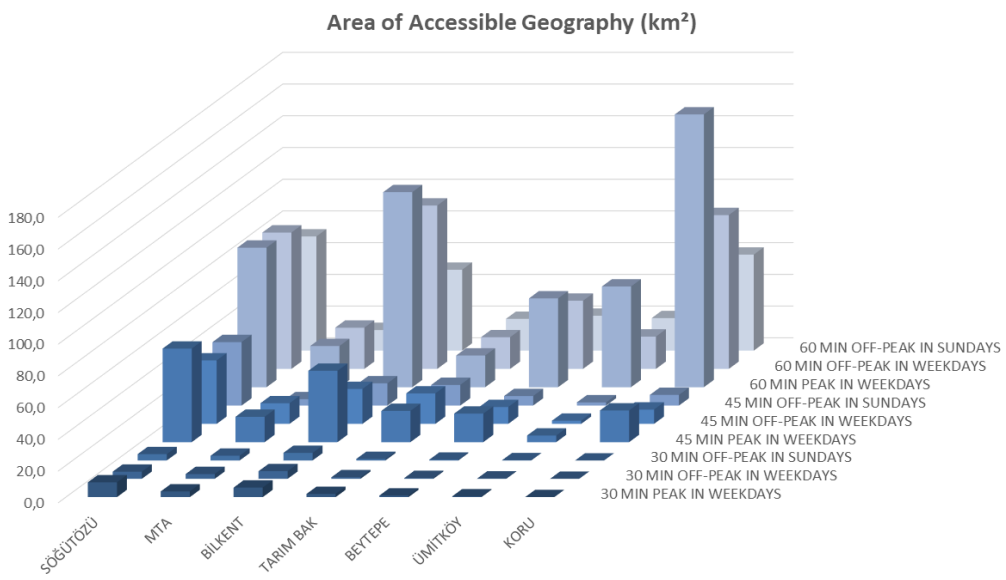


Figure 4.32 Area of Accessible Geography Around Each Station

The graph in Figure 4.31 shows the maximum distances (in km) accessible from each stations while the graph in Figure 4.32 displays the total area (in km^2) of the geography accessible from each stations. The Y axises of the graphes show how the accessible area around the stations changes as moving from Kızılay to Koru and the Z axises show how the accessible area changes on different days and times under the assumptions of 30-45-60 minutes of travel time budgets.

Having examined the Y axises of the two graphes in relation to each others, a general downward trend in the maximum distances that can be accessed in 30 minutes travel time is observed as going from Söğütözü –which is the one nearest to Kızılay- to Koru station is observed. Moreover, the Koru station itself is not accessible within a 30 minutes travel time in off-peak hours in weekdays and in Sundays because it takes 31 minutes to reach Koru from Kızılay station by train travel. Although the time cost of reaching Koru station is 29 minutes in peak-hours in weedays, there is still no accessible area around as the remaining one minute does not attain for egressing from the station. It is possible to access a maximum distance of 2 km to the station in 30 minutes travel time in WK17 in Söğütözü –the first transfer station on the line. Changes in the total area of accessible geography is also similar to those in the maximum accesaible distances. The area of accessible geography around Söğütözü station is 9,3 km but falls to 2 km around Danıştay station and to 1 km around Ümitköy station. Finally there is no area accessible within the given time limit around Koru –the last station on the line. That is, the effect of the travel time budget constraint on the accessible geography is clearly seen, which was also observed on the maps above. It is also recognized that the pattern of accessible area varies at peak and off-peak hours in weekdays and off-peak hours in Sundays. The waiting time for busses when transferring from stations in WK17 is always shorter than those in other days and hours since the service frequency of all the busses are higher in WK17.

The maximum distance that can be accessible when the travel time budget is assumed as 45 minutes is 5 km to the Söğütözü station, 3.5 km to the MTA, 7 km to Bilkent, 2,8 km to Danıştay, 7 km to Beytepe, 4,5 to Ümitköy, and 5,5 to Koru station in WK17. So, it is not verified that the accessible area within a given time gets narrower

as going outer. However, it is also seen both on the graph and the previous maps that the size of the area covered by accessible geography around stations becomes larger as moving forward expect for the MTA and Danıştay stations when the corresponding areas of accessible geography are considered. There are two points to be noted: The first is that the higher distance to the stations that can be accessed does not always indicate a larger accessible area around them. Thus the Söğütözü accessible area extending up to a 5 km distance to the station covers a 59 km^2 area in total while the Bilkent accessible area up to 7 km is 45 km^2 and the Koru accessible area up to 5,5 km is an area of 20 km^2 in total in WK17. The potential reasons for such a missmatch are the varying characteristics of spatial structures, sizes and road networks of the settlement areas served by each stations. The settlement area which is linked to the metro line through MTA station is much more smaller than that of others. Therefore, the accessible area around MTA remains narrower than the others even if there is no travel time limitation. Similarly, the furthest location that can be accessed around Danıştay station –which provides links only to the City Hospital campus area- is to be smaller than many others without any travel time limitation. Yet the trend of narrowing accessible area as going outward from the departing station is not filtered by the two exceptions. It is seen that the time budget has limited the accessible geography to an area of 20 km2 around Koru station in WK17. The same trend is also valid for the other days and hours. The accessible area in WK14 is 40 km^2 in Söğütözü but falls to 22 km^2 in Bilkent, to 11 km^2 in Beytepe, and to 9 km^2 in Koru.

The maximum accessible distance around the stations except for MTA and Danıştay stations becomes longer outwards rather than getting shorther under the assumption of 60 minutes travel time budget. The farthest location to be reached from Söğütözü station is at 5,5 km distance, which rises to 11 km to Bilkent, 14 km to Ümitköy, and 17 km to Koru station in WK17. The total area of accessible geography created by these distances is 88 km^2 around Söğütözü, 123 km^2 around Bilkent, and 172 km^2 around Koru station. Accessible area sizes around MTA and Danıştay stations do not change in WK14 and in WKN14, which means that the accessible areas of 26

km^2 and 20 km^2 has remained constant even if the time cost of travel is reduced. It is because all the bus stops have already been accessible in shorter travel times than 60 minutes. Consequently, the accessible areas around stations is not only shaped by travel time budget but also by the size and spatial forms of the settlements which are served by each station.

The size and spatial forms of settlement areas served by each station also determines the total number of bus stops within that area and those within accessible area as well as how the directly or indirectly the bus routes link the settlement area to the station. The larger the settlement that serviced by a station the higher number of bus stops within that area is expected to be accessible. Similarly, the number of stops accessible through a station is expected to be low where the serviced settlement area is not adjacent to the station. Therefore, the numbers of bus stops that are accessible from each station within the given time budgets and its ratio to those of all available bus stops linked to each station is to be regarded as two measures of how existing integration infrastructure cope with the geography.

The numbers of accessible bus stops and its ratio to the total numbers of bus stops linked to each station are given in the graphes in Figure 4.33 and Figure 4.34. It is remarkable on Figure 4.33 that the MTA and Danıştay stations –which were described as exceptions in the previous graphs- are also expections in terms of the number and ratio of accessible bus stops. These stations are those providing access to the least numbers of stops (13 and 10 in WK17 respectively) followed by Beytepe Station (31 in WK17). The number of bus stops accessed from Söğütözü, Bilkent, Ümitköy, and Koru stations tend to decrease as going outward under the time budgets of 30 and 45 minutes, while there is an overall rising trend under the time budget of 60 minutes. Koru station is the one providing access for higher numbers of bus stops than all other stations in 60 minutes travel time but it is also the station with the lowest rate of accessible bus stops. In other words, the number of bus stops connected to the Koru station is so high that the ratio of accessible bus stops is the lowest even though it provides access to the highest number of stops within the given travel times. The same is valid for Ümitköy station, where the ratio of accessible bus stops even

lower than that of Koru station. Söğütözü, MTA and Danıştay stations on the other hand provide access for all the stops linked to them (100%) in 60 minutes of travel time in WK17, WK14, and WKN14.

In peak hours in weekdays –when the public transportation services are offered by the highest standards- within 60 minutes which is the highest travel time budget, 29% of the stops linked to Bilkent station is unaccessible. This rate rises to 21% in Beytepe, to 78% in Ümitköy, and to 64% in Koru station. Moreover, the rates of unaccessible stops in 60 minutes travel time are even higher in WK14 and WKN14 than in WK17.

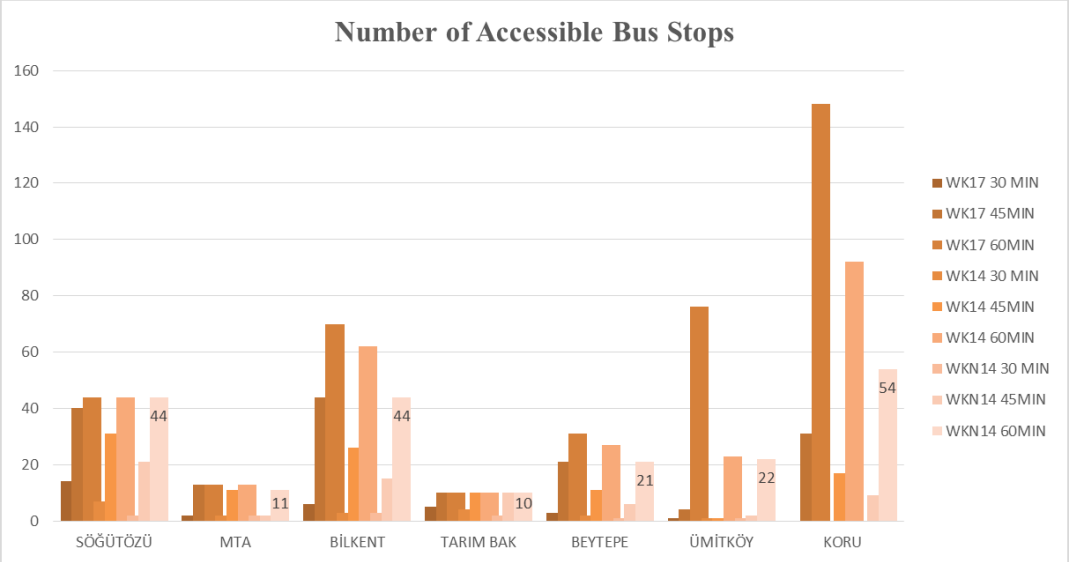


Figure 4.33 Number of Bus Stops Accessible from CBD in Constant Travel Times By Stations

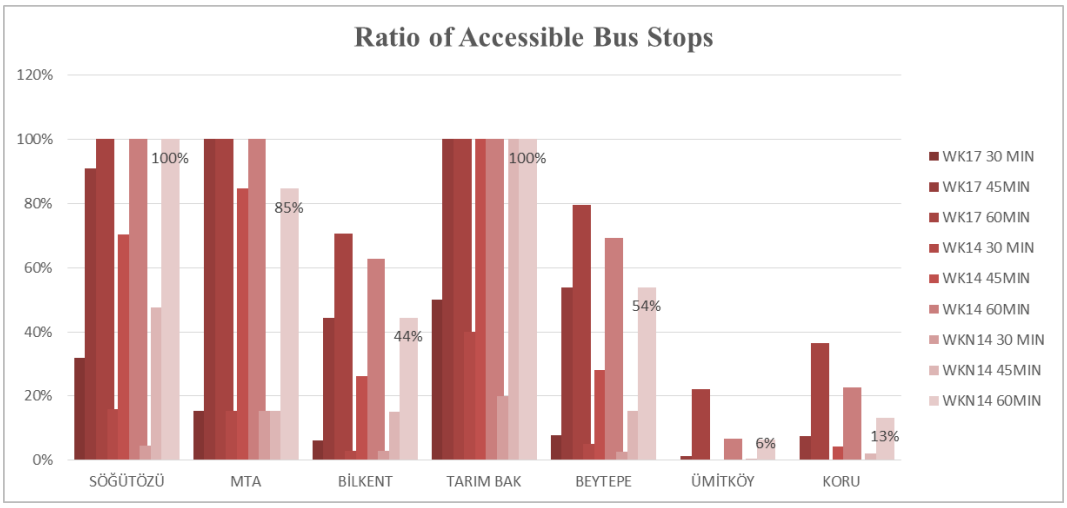


Figure 4.34 Rate of Bus Stops Accessible from CBD in Constant Travel Times By Stations

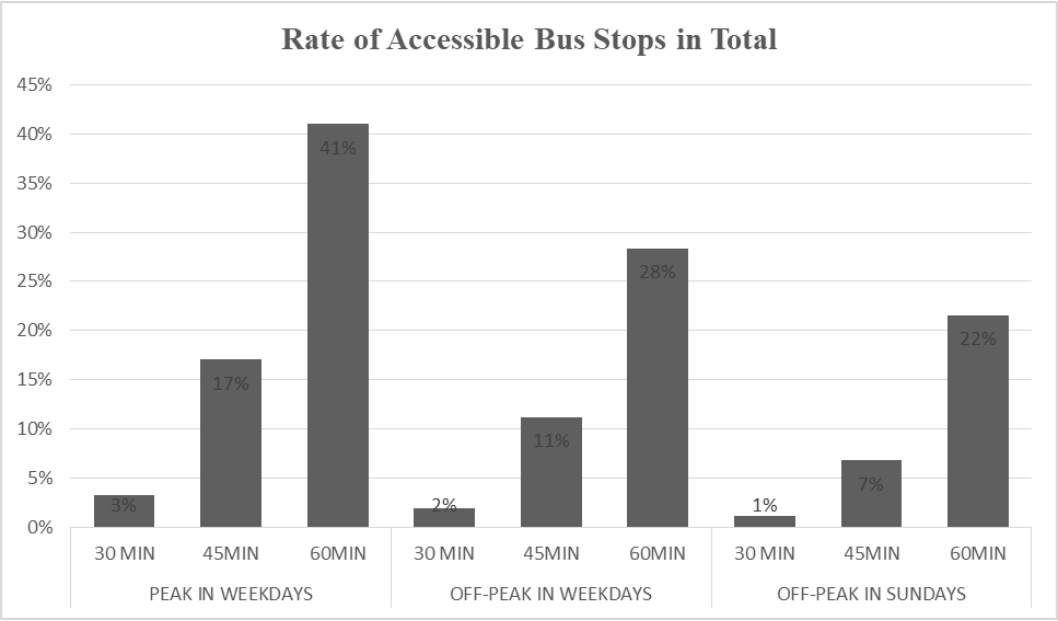


Figure 4.35 Rate of Bus Stops Accessible from CBD in Constant Travel Times (in Total)

The rates of the total number of bus stops accessible from Kızılay by means of the integrated system of Kızılay-Koru metro line and feeder buses within the given travel time budgets in WK17, WK14, and WKN14 to the total number of stops linked to the metro line through any station are revealed in the graph in Figure 4.35. Accordingly, there is almost no arrival stop that can be accessed from the station to which it is connected in 30 minutes travel time. Specifically, 3% of the bus stops that are linked to metro line is accessible in 30 minutes in WK17 as the frequency of bus services is a little higher in WK17. However, the rate is 2% in WK14 and 1% in WKN14. There is still only 17% of the stops accessible in WK17 –which falls to 11% in WK14 and to 7% in WKN14- although the accessible area has expanded when the travel time budget is assumed as 45 minutes. Even the half of the stops which have linked to metro line is not accessible under the highest travel time budget of 60 minutes. It is possible to access 41% of the stops in WK17, 28 % of those in WK14, and 22% of those in WKN14 in a 60 minutes travel time. The law rate of accessible stops especially in Ümitköy and Koru (22%-36% respectively) resulted that only 41% of all the stops have a connection to metro line is accessible in 60 minutes despite Söğütözü, MTA and Danıştay stations provides 100% access to the linked stops.

In this section, the geography that is accessible from the city center through the overall network consisting the metro line and its feeder bus lines in 30-45-60 minutes travel time constraints are exhibited as guided by the first and second sub-questions of the research. It is also explored how the accessible geography is varied in peak and off-peak hours in weekdays and off-peak hours in Sunday in terms of both the spatial pattern and statistical measures. Regarding the third sub-question, it is explored that the accessible geography varies in peak and off-peak hours in weekdays and Sundays based on the system facilities of multimodal integrated transit. The geography that is accessible from the city center by means of Kızılay-Çayyolu metro line and its feeder bus lines is wider in peak hours in weekdays than the others since both the metro and bus services are provided more frequently which decrases the waiting time within a journey. The schedule of the transit systems is

therefore the crucial factor determining the changes in accessible geography in varying days and times. The spatial pattern of accessible geography shrinks as going from the center towards the outer stations as the travel time to reach the outer stations increases and remaining time for travelling to final destinations by feeder buses falls.

The analysis so far has resulted in defining only the accessible geography based on the relation between total travel time cost and the given travel time budget although the total costs for each travel are obtained by summing up the costs of each parts of it, which indicates the time-geographic appraoch. It is possible to draw many conclusions on how the integrated system of metro and feeder bus lines creates accessibility regions, how they change in peak and off-peak hours and in weekdays and Sundays, etc. which are detailly explained in the conclusion part. However, it does not provide a finding on how the time cost of a travel is allocated on each section of mobility in space from the origin to the final destinations. In other words, there is no inference about the composition of the total travel time cost in space-time paths of the journeys from Kızılay to the final destinations, which is declared as one of the aims of the thesis. To do this, there is a need for both spatial and statistical analysis of time cost data that is filtered as numbers in the background of accessible geography maps. The allocation of time cost within the parts of travels which constitute the accessible geography will be explored in the following section. Thus, the aspects in which the integrated system of metro line and feeder busses is weak in coping with geography is to be identified. How time cost affects mobility in space and accessible geography along certain routes under a fixed time budget will also be revealed by the time-space path method.

4.4.2 Determination of Travel Time Allocation

This part of the analysis provides answers for the fourth and the fifth sub-questions of the research by exploring how the travel time is allocated in parts of a journey from Kızılay –the city center- as the origin to the final destinations and how accessible geography is constrained in relation to time cost of each part of a journey.

The allocation of travel time demonstrates the average time costs of each activities within journeys from an origin to a final destination, such as waiting, in-vehicle travelling, egress, and walking to the final destination. Determining the travel time allocation on the parts of a journey helps assessing the system performances of metro and feeder bus routes and schedule integration among them as well as indicating their possible effects on accessible geograhy within a given travel time budget. It also provides basis for "time" or "duration" data of each activity which is one of two required data for time-space path analysis.

The travel time budget is a factor which has a direct effect on allocation of travel time of a journey. The shorter the travel time budget is, the earlier the journeys will be ceased by the time constraint. Therefore, the time allocation of journeys within 60 minutes –the longest travel time budget assumed- in WK17 is to be examined under groups by the stations to which they are linked. The bus routes originated from each stations and schedule integration among the trains and the busses will be evaluated based on the travel time allocation.

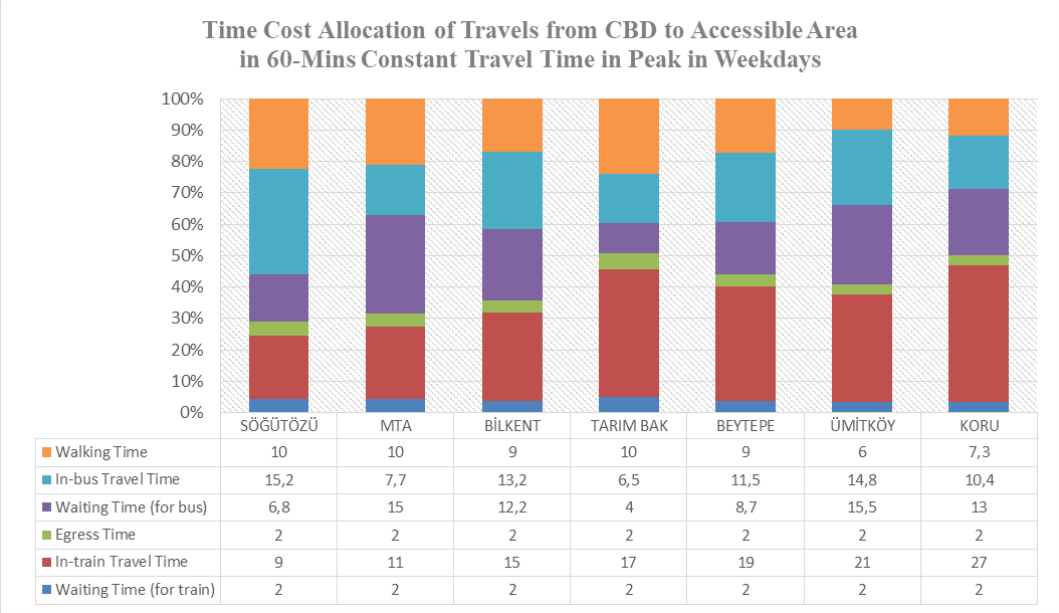
The Figure 4.36 below shows average waiting time for train in Kızılay, in-train travel time, egress time, waiting time for bus, in-bus travel time, and walking time of overall travels through each station in a total travel time budget of 60 minutes. Accordingly, the average waiting time for bus in Kızılay station is 2 minutes. The time cost of reaching the stations by in-train travel time inevitably increases as going forward to Koru. The in-train time cost of reaching Söğütözü station which is the nearest to the origin is 9 minutes, which rises to 27 minutes in Koru –the furthest station. Time costs of egress from the arrival stations and access to the departing stops is assumed as 2 minutes at each station. The cost of waiting for transfer busses –which is the next activity- varies based on schedules of bus lines linked to each stations. However the share of waiting time encountered when transferring from train to busses is so close to in-train travel time except for the journeys through Danıştay and Beytepe station. There is an average of 15 minutes waiting cost for the secondary mode in MTA station after an 11 minutes travel in train. Similarly, a 16 minutes of average waiting cost is exposed to after a 21 minutes of in train journey to reach

Ümitköy station. It is considered as an operational weakness that the waiting time to transfer from metro –which is the primary mode-to the feeder lines which provide access from metro to the final destinations is almost the same as time cost of travelling in the primary mode. Furthermore, average time costs of in-bus travelling –which is the next activity of the whole journey- are almost the same as that of in-train travel –which is the primary line- except for the travel through Danıştay, Beytepe, and Koru stations. The time cost of journeys through Söğütözü station is distributed on in-train tavel by 22% and on in-bus travel by 35%. The travel time cost of in-train and in-bus travel's pays are 20%-18% in MTA, 24%-22% in Bilkent, 34%-26% in Ümitköy stations. But the 60 minutes of travel time budget limits the lenghts of in-bus travels shown in the graph. It will also be revealed in the next graph that the rates of in-bus travels are much more higher for journeys to the all stops linkted to metro stations without any time constraint. The average time budget remaining after the arrival stops are accessed represents the maximum walking time from these stops to the final destinations. The share of average walking time in the total travel time cost ranges from 10% (in Ümitköy) to 24% (in Danıştay). Moreover, these amount of average bus waiting times are even higher in WK14 and WKN14. Regarding the graph, it is obvious that less than half of the total travel time of journeys by means of the integrated system of metro line and feeder busses within the area accessible in a 60 minutes travel time belong to the in-train travels.

The average waiting time for train, in-train travel time, egress time, waiting time for bus, in-bus travel time, and walking time within the journeys through each stations without any time budget restriction are revealed on the graph in Figure 4.37. The amount of waiting time for train, in-train travel time, and egress time remains the same as those in area accessible in 60 minutes as they are fixed for each station. But the in-bus travel time and waiting time for busses have changed as trips by longer bus lines are included when there is no time budget constraint. Nevertheless, travel time cost distribution of journeys through Söğütözü, MTA and Danıştay stations remained the same since all the stop linkted to these stations have already been accessible within 60 minutes. But the average in-bus travel time in journeys through

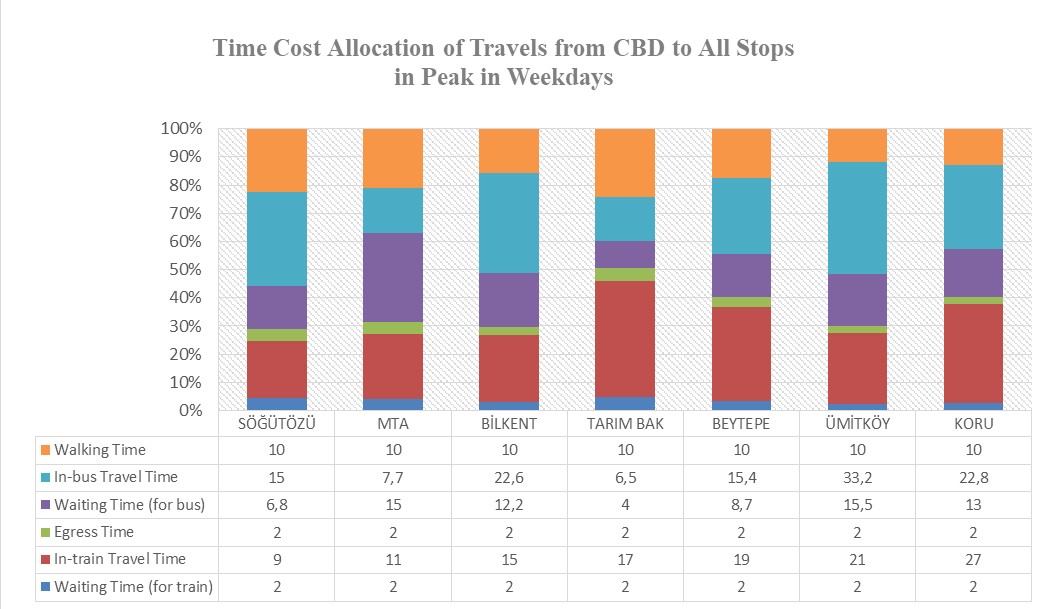
Bilkent, Beytepe, Ümitköy, and Koru stations increase while the shares of in-train travel time and bus waiting time decreased. Thus, the characteristic of the metro line being the primary component of the integrated system is weakened. Specifically, the shares of in-bus travel time costs and in-train travel time costs of the whole journeys are respectively 36%-21% in Bilkent, 40%-22% in Ümitköy, 28%-34% in Koru stations, where the share of bus waiting time is approximately 20% of the total travel time cost. Consequently, Danıştay and Beytepe stations are the most ideal ones regarding the feeder characteristics of in-bus travel time and predominancy of in-train travel time as the primary mode.

The amount of travel time cost in minutes rather than their shares in total travel times are also given in Figure 4.38 in order to put forward how the parts of travel time costs have changed from Söğütözü to Koru –the last station.



	SÖĞÜTÖZÜ	MTA	BİLKENT	TARIM BAK	BEYTEPE	ÜMİTKÖY	KORU
Walking Time	10	10	9	10	9	6	7,3
In-bus Travel Time	15,2	7,7	13,2	6,5	11,5	14,8	10,4
Waiting Time (for bus)	6,8	15	12,2	4	8,7	15,5	13
Egress Time	2	2	2	2	2	2	2
In-train Travel Time	9	11	15	17	19	21	27
Waiting Time (for train)	2	2	2	2	2	2	2

Figure 4.36 Time Cost Allocation (%) of Travels from CBD to Accessible Area in 60-Mins Travel Time in Peak in Weekdays



	SÖĞÜTÖZÜ	MTA	BİLKENT	TARIM BAK	BEYTEPE	ÜMİTKÖY	KORU
Walking Time	10	10	10	10	10	10	10
In-bus Travel Time	15	7,7	22,6	6,5	15,4	33,2	22,8
Waiting Time (for bus)	6,8	15	12,2	4	8,7	15,5	13
Egress Time	2	2	2	2	2	2	2
In-train Travel Time	9	11	15	17	19	21	27
Waiting Time (for train)	2	2	2	2	2	2	2

Figure 4.37 Time Cost Allocation (%) of Travels from CBD to All Stops in Peak in Weekdays

The average waiting time for train and egress times are equal and constant for each all the stops linked to each station. But the average in-train travel time inevitably increases from 9 minutes to 27 minutes as going from Söğütözü –the nearest station to departure point- to Koru –the farhtest station. It is also seen that the average bus waiting times vary between 4-15 minutes at each station regardless of the distance to the origin. There are 7,7 minutes of in-bus travel time cost in journeys through MTA, and 6,5 minutes in those through Danıştay stations instead of very long feeder bus lines since the settlement area within which the arrival bus stops departed from these stations are located are smaller and more compact than others. The journeys through Bilkent, Ümitköy, and Koru stations on the other hand have an average in-bus travel time costs of 23-33-23 minutes respectively when the journeys from these stations to the all linked stops are considered. Yet the average in-bus travel times of journeys to the all linked stops and to only those in 60 minutes of access area differ. It does not vary between the journeys from Söğütözü, MTA, and Danıştay stations since all the arrival stops linked to them have already been accessible in 60 minutes of travel time. The difference in average in-bus travel time of journeys to all the linked stops and to those in 60 minutes of access area is highest in the journeys through Bilkent, Ümitköy, and Koru stations. This means that the journeys through Bilkent, Ümitköy, and Koru stations are significantly limited by the travel time budget of 60 minutes while it does not constraint the journeys through Söğütözü, MTA, and Danıştay stations. It is such that the share of in-bus travel time in the journeys from these station to all the arrival stops goes much more higher than the share of in-train travel times. In addition, the average time cost of waiting for bus at Söğütözü, Bilkent, and Ümitköy stations are almost the same as the average time cost of in-train travels. Moreover, the time cost of bus waiting in MTA station is higher than the cost of in-train travel time to reach the station.

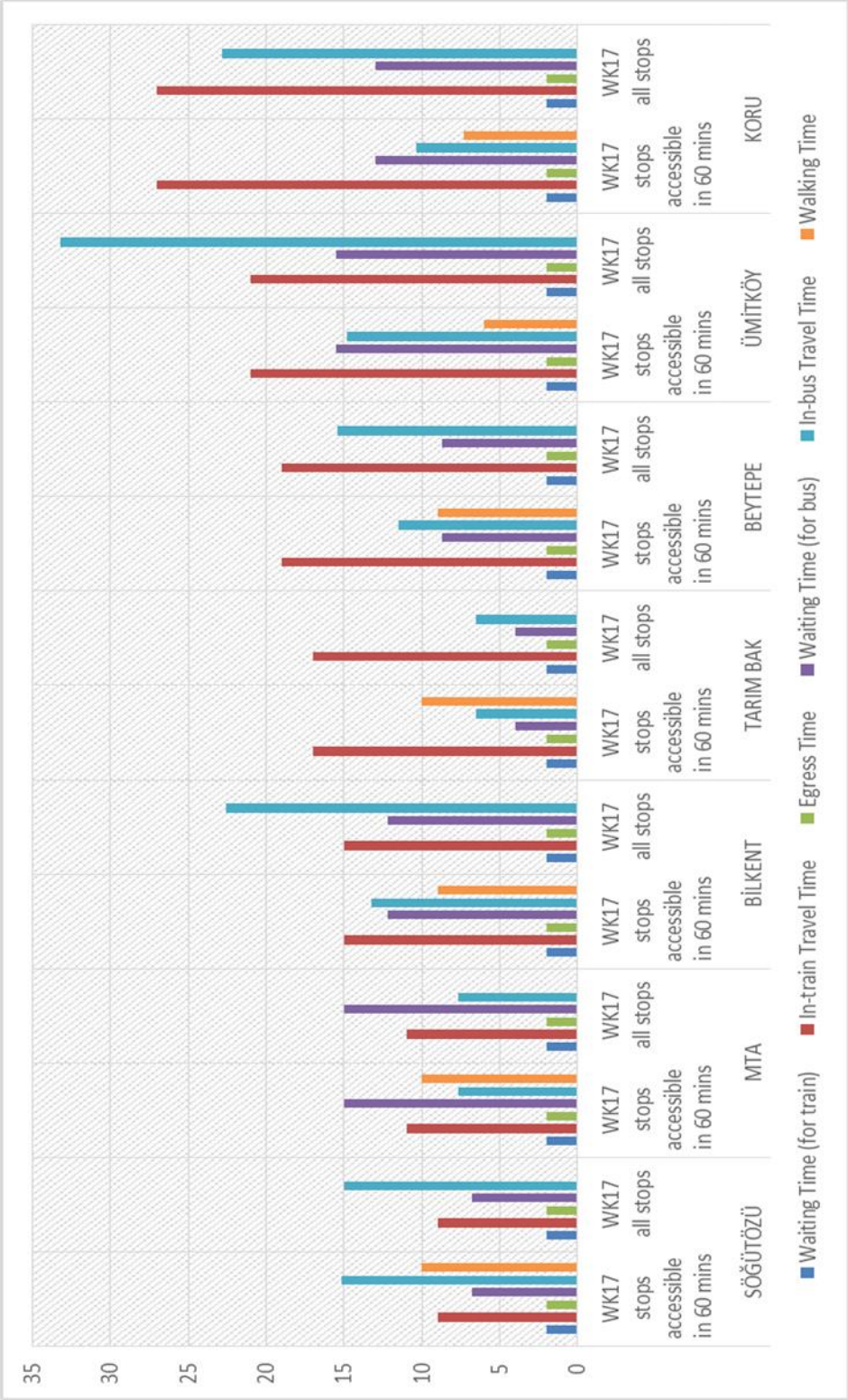


Figure 4.38 Average Time Costs (Minutes) of Travel Segments

Having discussed the average time costs of the sections of travels from Kızılay –the city center- to final destinations, the following time-space paths represent how the allocation of travel time on the sections affect mobility in space along certain routes. It also put forward how the accessible geography is limited by the relation between time costs for each sections and a given amount of travel time budget.

The sections of each travel have two essential components to be defined by: One is activity locations (control points) in terms of "time" and "space", and the other is the movement paths connecting temporally adjacent activities as explained in the methodology part. The minimum information available at each control point is its location and the time when location was recorded. Therefore, it is not possible at least in the context of this thesis to analyze travels from Kızılay to all the bus stops which are linked to any station on the line. So, the travels including transfer from metro to feeder busses on certain routes from each station on the metro line are determined as the samples for time-space path analysis. The feeder bus lines that transport highest number of passengers from each station to the neighborhoods are determined as the samples because these bus lines are the backbones of feeder system of each station. According to the average daily number of transferring passengers to each station on the metro line in 2019, the bus number 132 which transports 330 transfer passengers (38% of total transfers from Söğütözü station) from Söğütözü, the bus number 167 transporting 83 transfer passengers (100%) from MTA, the bus number 111 transporting 706 transfer passengers (58%) from Bilkent, the bus number 113 transporting 983 transfer passengers (97%) from Danıştay, the bus number 564 transporting 1334 transfer passengers (48%) from Beytepe, the bus number 507 transporting 800 transfer passengers (20%) from Ümitköy, and the bus number 590 transporting 857 transfer passengers (12%) from Koru station are the bus lines the time-space paths of which are to be analysed.

The control points of journeys on these routes are the terminals at which the travels are interrupted by a need for exchange between the modes. Accordingly, the Kızılay metro station is the first terminal which is followed by the arrival metro stations. The departing and arrival bus stops of feeder bus lines are the next two control points

which are followed by the final destination of the travel. But the final destinations are not included as a control point on the time-space paths because those of representative journeys are unknown in terms of exact locations. The bus stops which are at the farthest distance to the stations are regarded as the arrival bus stops on the sample routes. The location information of all the control points are expressed in their eaclidean distance to the previous control point and marked on a two-dimensinal plane. The time information of interruptions of journeys on these control points are also expressed in terms of the total time cost for reaching there, which are obtained from Google Transit. The time and location information of the control points are determined for the peak hours in weekdays only because it provides the largest size of accessible area in all cases.

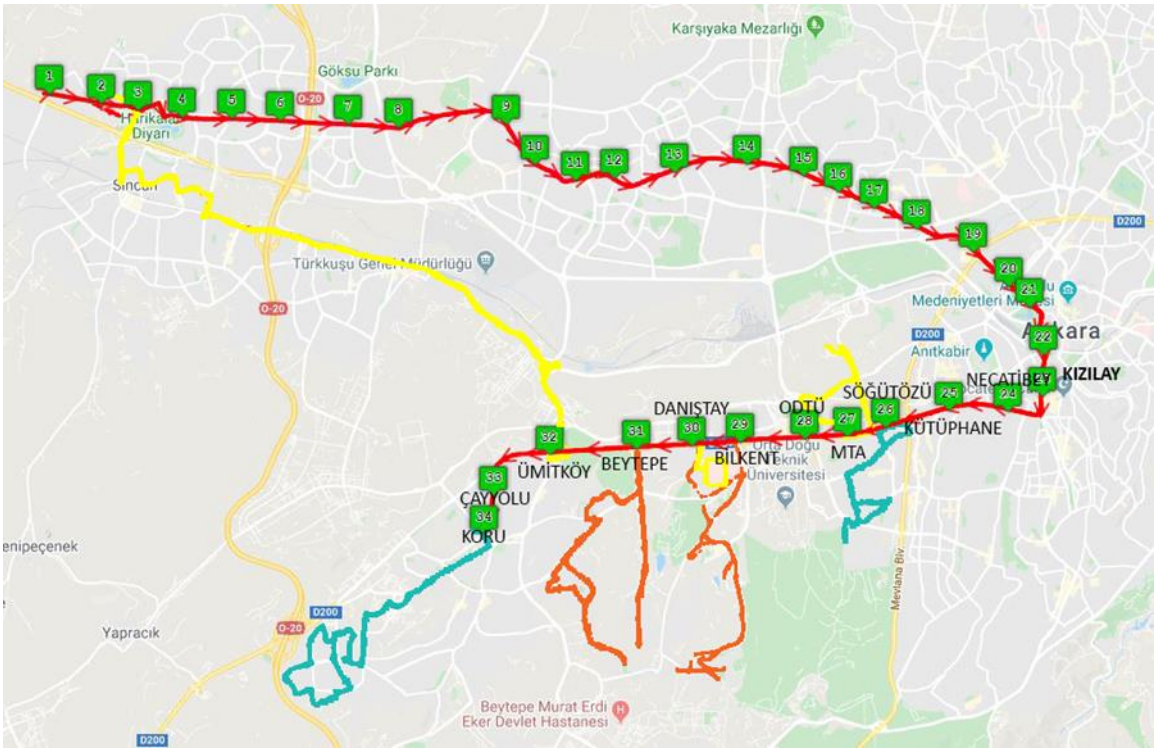


Figure 4.39 Map of Feeder Bus Lines with Maximum Passenger Volume

Source: Produced by the author based on data sourced by EGO, n.d.

Given the control points with time and space information, the path segments are created by interpolation between adjacent control points using time as a parameter. The space-time paths of sample routes are constructed by combining the paths segments with the control points, which are available on the graphs below. The control points are represented by the yellow marks the corresponding time and space information of which are available on x and y axises respectively. The control point at the end of the path stands for the arrival stop which is the furthest one on the sample bus line. The dashed line in gray shown as a continuation of the path symbolizes the time-space trend of the line in the case that the limitation of the accessible area due to the size and form of the serviced settlement area or the length of the bus line is eliminated. The travel time budgets of 30 and 60 minutes are shown in red line which intersects either the path itself or the extension of the line at the point where the travel time cost so far is equal to the given budget. The corresponding location is the furthest distance that can be accessible from Kızılay by means of the integrated system of metro and the feeder bus line under the given travel time budget. The red markings at the intersection points designate the "time" and "space" at which the travel time constraint ends the journey.

The starting point of each journey is Kızılay station where the average waiting time for train is 2 minutes in peak hours in weekdays. Therefore the location is stable at Kızılay station during the first two minutes of the journeys. Then the in-train travel starts at the second minute and lasts for 9-27 minutes depending on the distance of each station to the origin –which is Kızılay. Having been reached the arrival station at certain distances, the second movement path for accessing the bus stops at which the feeder busses depart is in the same direction and the same size in each case. It is because the distances between arrival stations and departure stops are assumed as 200 meters and the walking time including the egress from stations are assumed as 2 minutes for all the cases. After two minutes of mobility, there is another stability not in time but in space during the waiting time for the busses which varies according to the servicing frequency of the lines. Then the last segment of the path goes from the time and space when the bus is taken to the time and space of the arrival stop.

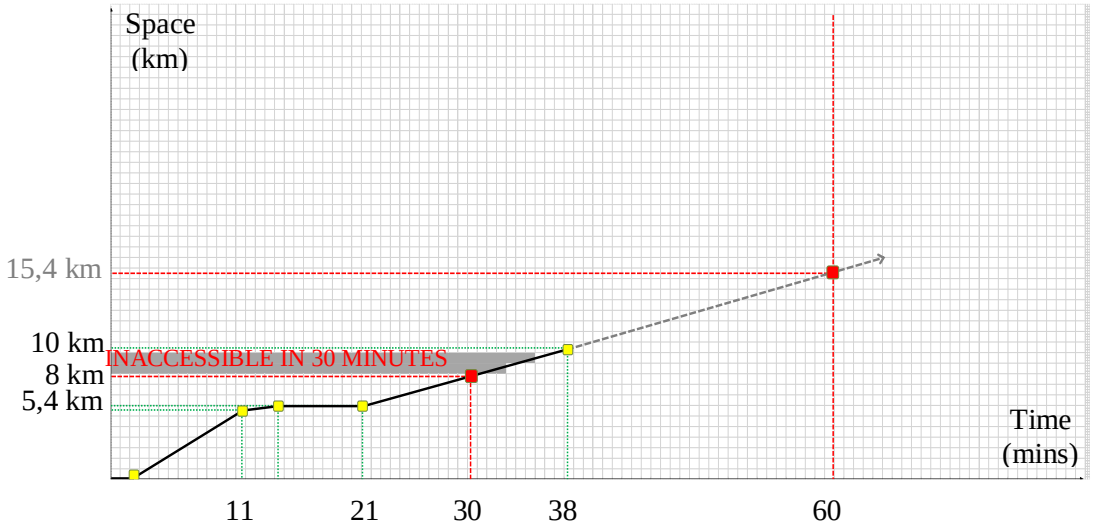


Figure 4.40 Space-Time Path of Travels Through Söğütözü Station

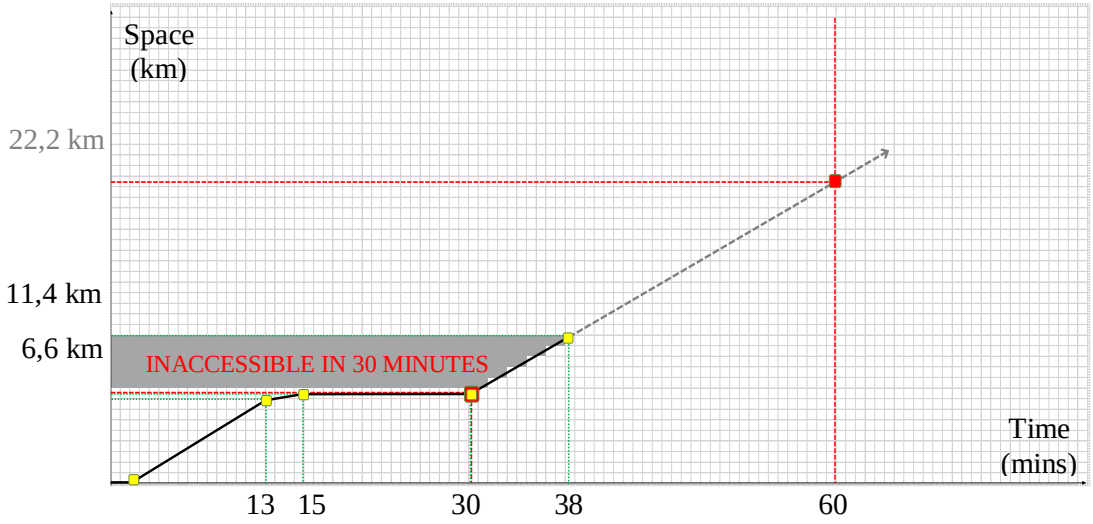


Figure 4.41 Space-Time Path of Travels Through MTA Station

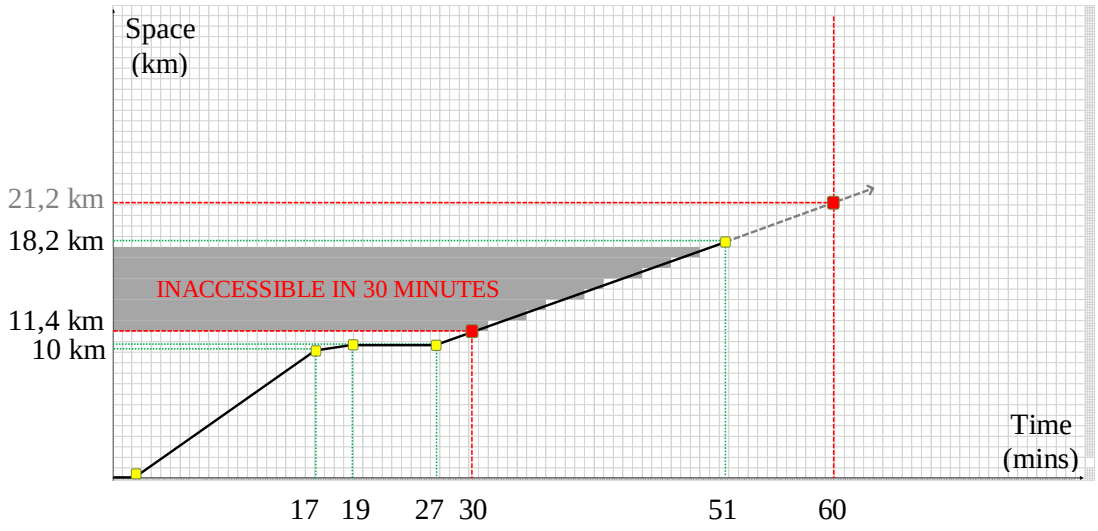


Figure 4.42 Space-Time Path of Travels Through Bilkent Station

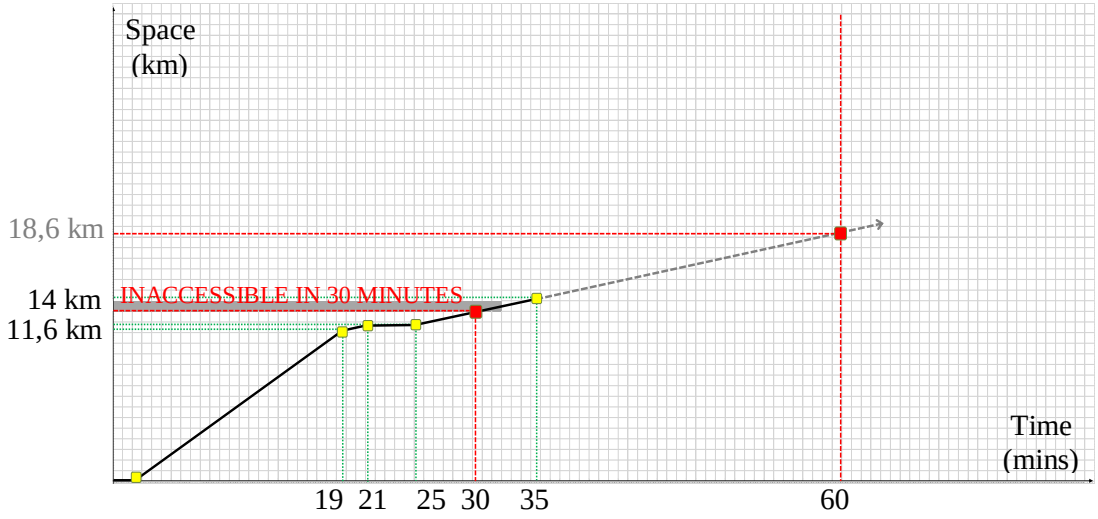


Figure 4.43 Space-Time Path of Travels Through Danıştay Station

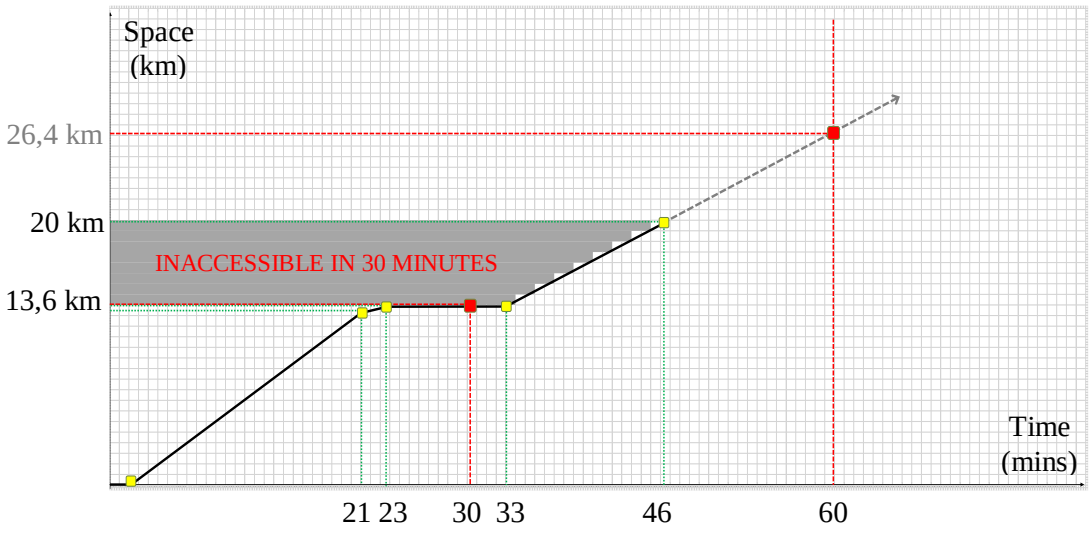


Figure 4.44 Space-Time Path of Travels Through Beytepe Station

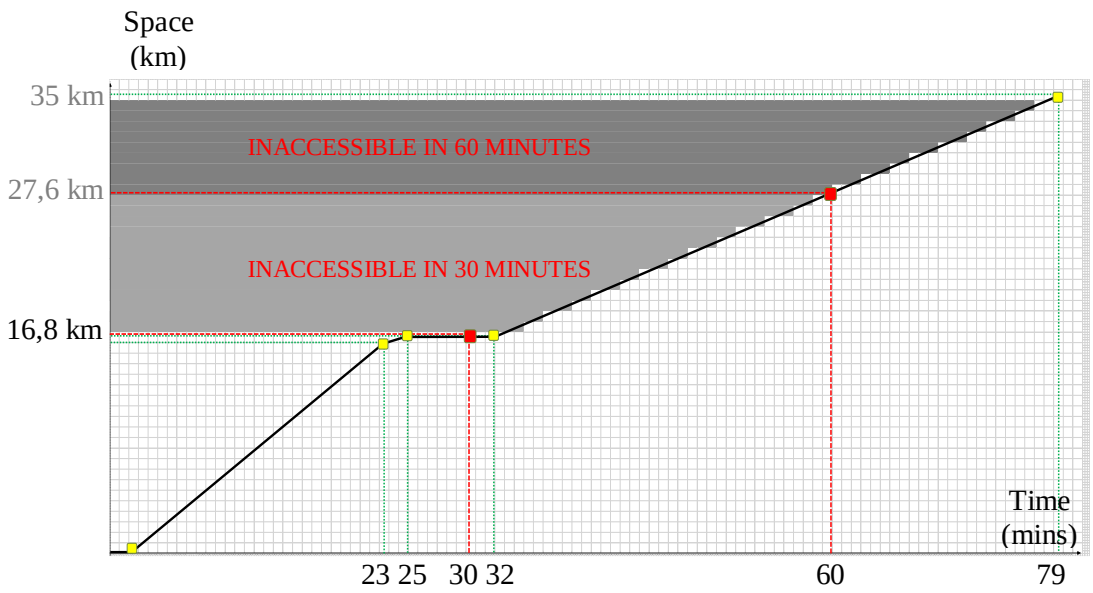


Figure 4.45 Space-Time Path of Travels Through Ümitköy Station

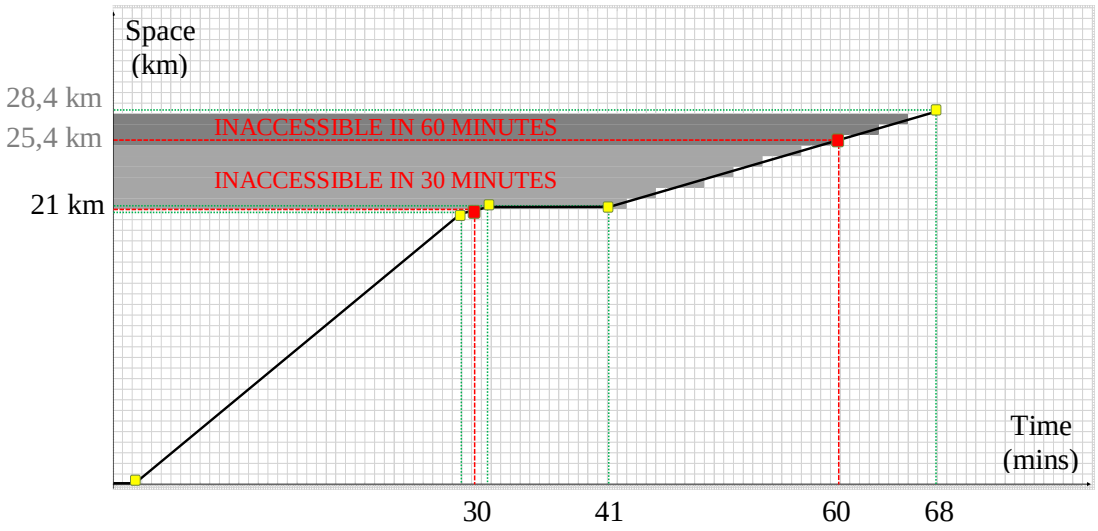


Figure 4.46 Space-Time Path of Travels Through Koru Station

The time cost of in-train travel differs in each case based on its distance to the origin. The distance of Söğütözü –the first station- to Kızılay is 5,4 km which is accessed in a 9 minutes of in-train travel. The distance to be overcomed becomes 6,6 points in MTA –the next station- which takes 11 minutes of in-train travel from Kızılay. But the travel time cost of in-train path segment rises to 29 minutes in journeys from Kızılay to Koru –the last station at a 19 km distance. Apparently, the path segments standing for in-train travel from Kızılay to the arrival stations are in varying lengths depending on the "space" and corresponding "time" but in approximately the same slope as it is a single metro line in operation.

The path segments for bus waiting activity also differs in each case depending on the servicing headway of the bus line. The space is constant along the path segment for bus waiting activity while the time runs which shortens the remaining time of total time budget. Accordingly, there is the longest path segment of 15 minutes in transfers from MTA, and the shortest path segment of 4 minutes in transfers from Danıştay station. Since the space is constant during the waiting time, the effect of the path segment on accessible geography is to be evaluated through how much does it occupy the overall travel time budget. The 15 minutes of average time cost of bus

waiting at MTA station constitutes the 50%-25% of total travel time budgets of 30 mins-60 mins, and the 40% of total travel time cost of accessing the last bus stop on the line. It is also observed that the time cost of bus waiting is higher than those of in-train and in-bus travels to reach the furthest stop to the station. However, the 4 minutes of average bus waiting time at Danıştay station occupies 13%-6% of the total time budgets of 30mins-60 mins, and the 11% of total travel time cost of reaching the furthest bus stop. It is concluded on the time-space graphes that the shorther the time spent on bus waiting, the higher the remaining time for moving forward on space, which means the larger accessible geography under the given time budget.

The next segment of the time-space path is in-bus travel part of the journey which starts when the feeder bus is taken and ends at "space" and "time"at which the arrival bus stop exists. The slope of the path segment that is formed by interpolating between these two control points, and the points where it intersects with the lines for time limits of 30 minutes and 60 minutes is crucially important in determining its effect on accessible geography.

The slope of this segment –the rate of the difference in space to difference in time at which the two control points exist- corresponds to operating speed of the bus lines. That is; the higher the line is sloping, the higher the operating speed of busses or the more direct the routes are. Accordingly, bus lines transferring from MTA and Beytepe stations are those having overcomed the longest distance per unit of travel time cost whereas the Söğütözü and Danıştay stations are those having overcomed the shorthest distance per unit. The characteristics of road network or the traffic density in the settlement units serviced by these bus lines could be the reasons for varying operating speed as well as the directness of the routes and the frequency of stops to get on/off the passengers. It is required a specific research to identify the role of each on changing bus operating speeds. However, the effects of these path segments on accessible geography is possible to be evaluated based on where they intersect with budget lines of 30 and 60 minutes. The intersection points corresponds

the “time” and “space” at which the journey is ended because they have reached the time budget constraint.

The travel time budget of 30 minute ends all the journeys on the sample lines before reaching the last arrival stop. The time budget in some journeys is even reached during the bus waiting activity before transferring to the bus. Thus, the areas that have integrated to the metro line through bus lines but are not accessed via metro station appear at certain distances along the each route due to the 30 minutes of time budget. These inaccessible areas are represented by the grey surfaces which are bordered by the “space” at which the 30-minutes budget line intersects the path, and the “space” of the last arrival stop on the bus line. Although the points where the journeys are ended are to be expressed in terms of “space”, sizes of the inaccessible areas are determined not only by distance but also by the path itself as the time constraint. Accordingly, the settlement unit that is serviced by the feeder bus lines from Danıştay station is the one least affected by 30-minutes time budget. The overall journey which could last up to a 14 km distance in total end at 12,8 km due to the time budget constraint. It is followed by Söğütözü station in terms of the size of inaccessible geography. The accessible geography extending up to 10 km in total is limited at the 8th km of the journey during in-bus travel due to 30-minutes travel time budget. The journey through MTA station on the other hand ends during 15-minutes bus waiting activity. It has already been revealed that the longest bus waiting time is observed at transfers to bus lines from MTA station. So, the length of the waiting time caused the accessible area to be limited to the transfer stop. Similarly, the 30-minutes time budget ended the journey including transfer from Beyetpe station within the 7th minute of the 20-minute of bus waiting. Therefore, a large area which is serviced by the feeder lines is inaccessible due to budget constraint. The transfer journeys from Ümitköy, the serviced area by which is one of those most affected by the 30-minutes time budget, end et the 5th minute of the 7-minutes bus waiting activity whereas those from Koru station end while walking to the transfer stop. This means that the size of inaccessible area is not only a result of the path segment of in-bus travel, but also a result of time spent in the earlier segments such

as waiting, walking and in-train travel. Hence, there are journeys which end while waiting for the bus or before reaching the transfer stop.

Having assumed the travel time budget as 60 minutes instead of 30 minutes, there is no time limitation appeared on journeys including transfer at many stations. That is, the journeys are completed without any time limitation if the furthest arrival stop on the sample lines are already accessible in 60 minutes. But it is not necessary for the sample lines –which transports highest number of transfer passengers- to be the longest ones. It is available on the accessible area maps given in the previous part whether the 60 minutes of travel time budget limits the accessible area along each line or not. But the time costs of each segments on journeys along the specified lines and their effects on the formation of accessible area are to be discussed on the time-space paths.

The 60-minutes travel time budget does not constitute a restriction on journeys through all the stations except for Ümitköy and Koru. The time budget constraint has no effect on the accessible area as there is no further stop on these lines accessing to which requires extra time budget. However, there are extensions of path segments from the last arrival stop forward showed in order to explore how the allocation of travel time on parts of the journey as the single factor shapes the accessible area when the other factors are eliminated. The point on time and space at which the extension line intersects the 60-minute time budget line indicates the limit of accessible area in the case of feeder bus line in infinite length.

Assuming the length of the bus line originated from Danıştay station -which requires the minimum waiting time in transfers to the bus- as infinite, the space at which the total travel time cost equals to 60-minutes time budget corresponds to a shorter total distance than all other cases. The only reason for overcoming the shortest distance in the same budget despite being mid-station where the least amount of time is needed for waiting the bus is that the in-bus travel segment of the path is the one with the lowest slope which means the operating speed is the least.

MTA, Bilkent and Danıştay stations are three consecutive stations. Although the total distance that is overcomed by the journeys including transfers through these stations is expected to increase since the in-train travel time increases and bus waiting time decreases as going to the next, it decreases due to the decreasing slope of in-bus travel segments.

Coming to the Ümitköy and Koru stations, the time budget of 60 minutes ended the journey through Koru at a shorter total distance because both the bus waiting time is higher and operating speed is lower in these journeys than those transferring from Ümitköy. As a result, the geography travelled over by the journeys through Ümitköy station reaches farther distances than those through Koru station. Then, a wider area -serviced by the feeder bus lines from Ümitköy station- is prevented to be accessible in a 60 minutes travel since the farthest stop linked to the Ümitköy station that could be accessible when there no time limitation is at a longer distance than the one linked to Koru station on the sample line. Consequently, it is inferred that the integration facilities in the service area of Koru station are utilized more efficiently.

In summary, the allocation of travel time within the parts of travels and its effects on the accessible geography, as put forward by the fourth and fifth sub-questions of research, is explored in this part. The fourth question seeking how the travel time is allocated on parts of a journey from the city center through the integrated multimodal transit system is answered by analysing the average time allocated for in-train and in-bus travels as well as waiting times, eggres times, and walking times as parts of a journey from city center to arrival bus stops as final destinations. Accordingly, it is determined that less than half of the total travel time of journeys by means of the integrated system of metro line and feeder busses within the area accessible in a 60 minutes travel time belong to the in-train travels. It is also remarkable that the share of waiting time for bus at interchange station ranges between 10%-30% of total travel time. The high share of waiting time when transferring from the primary mode –metro- to the feeder mode –bus lines- could be a strong reason for passengers to prefer travelling options which do not necessiate a transfer. The same factors are analysed also for the all possible journeys from the city center –Kızılay- to all arrival

stops of feeder bus lines, not only the ones within the accessible area in a 60 minutes of travel time. Considering travel from city center –Kızılay- to not only the arrival feeder bus stops within accessible area in a 60 minutes of travel time but also all the posible travels to all arrival stops of feeder bus lines, the share of in-train travel time decreases while the share of in-bus travel time increases. Thus, the characteristic of the metro line being the primary component of the integrated system is weakened. The waiting time for transferring to a feeder bus also takes travel times at high rates. The share of average bus waiting time are very close to the share of in-train travel time to reach the stations except for Beytepe and Danıştay Station. It is considered as an operational weakness that the waiting time to transfer from metro to the feeder lines which provide access from metro to the final destinations is almost the same as time cost of travelling in the primary mode. The difference in average in-bus travel time of journeys to all the linked stops and to those in 60 minutes of access area is highest in the journeys through Bilkent, Ümitköy, and Koru stations. This means that the journeys through Bilkent, Ümitköy, and Koru stations are significantly limited by the travel time budget of 60 minutes while it does not constraint the jourmeys through Söğütözü, MTA, and Danıştay stations. It is such that the share of in-bus travel time in the journeys from these station to all the arrival stops goes much more higher than the share of in-train travel times. The fifth sub-question seeking how the accessible geography is constrained in relation to travel time allocation is answered through space-time paths of observed journeys from city center to arrival stops of feeder bus lines which have the highest passenger volume from each stations. The space-time paths showing the segments of a journey based on changes in space and travel time allocation have indicated that the shorther the time spent on bus waiting, the higher the remaining time for moving forward on space, which means the larger accessible geography under the given time budget. The travel time budget of 30 minute ends all the journeys on the sample lines before reaching the last arrival stop. It is also concluded that the size of inaccessible area is not only a result of the path segment of in-bus travel, but also a result of time spent in the earlier segments such as waiting, walking and in-train travel. Hence, there are journeys end while waiting

for the bus or before reaching the transfer stop. The size of the settlement unit that is serviced by the feeder bus lines and the length of these lines are also factors determining the accessible geography around each stations. But the extensions of path segments from the last arrival stops forward present the time and space at which the accessible area would be limited by the time budget as the single factor in the case of feeder bus lines are in infinite lengths.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

The current thesis on multimodal integration in transit system based on CBD accessiblity has aimed to contribute to develop policies for multimodal transit integration by addressing the limits of accessibility regions that an integrated transit system creates under certain constraints. Specifically, it has intended to assess the performance of an integrated transit system consisting of Kızılay-Çayyolu metro line and local bus services linked to the line in providing accessibility from the CBD –Kızılay- to urban activity locations along the transit corridor. In this general framework, the research question of "How the system facilities of integrated multimodal transit system affects the accessible geography?" including the changes in accessible geography in relation to schedule and route integration between the two modes have tried to be resolved. The concept of "accessible geography" refers to the spatial and statistical measures of the overall area that could be accessible from the CBD –central business district- by travelling on the means of integrated system of metro line and its feeder bus lines.

The literature review and an overview of the experiences on improving the multimodal integration in transit systems in case cities have provided a background knowledge of concepts and their practices in case cities in the world that helped to assess the case of Ankara. It is basically concluded from the literature review that overcoming the space under certain constraints is the ultimate function of transportation service according to the theory of transportation geography. The amount of space that is overcome within a given time is considered as the most basic measure of transportation. Transportation activities are eventually for overcoming space so that urban activity locations become "accessible" by users within particular constraints. So, the quantity and quality of service provided by a given transportation system determine how much the serviced area/geography is accessible by the users.

Regarding the integrated multi-modal transportation, some particular keywords are attained from the related literature. “Seamless operation” and “direct travel” are the two key concerns of integrated transport whereas “walking time”, “waiting time” and “distribution of travel times” are commonly identified as main components of “transfer penalty” referring to cost of travellimg with transfers. It is also concluded that there is a broader motive for potential users to rationally decide whether an integrated multi-modal transit system requiring transfers provide a “benefit” to them. The role of integrated multi-modal transit systems therefore is to benefit the users by enabling the desired “access” to various destinations in space despite the physical and operational limitations. This point of view has constituted the approach of this study to assess the integration performance of the case transit system.

The knowledge obtained from overviewing multimodal integration in transit systems in Zürich and Melbourne includes the integration policies and their experienced results in two different city in different parts of the world which have quite different population densities but almost the same rate of car ownerhip at a quite high level. Zürich, where the population density (906 per/km^2) and share of public transit use (46%) is at a much more higher level despite the 495‰ of car ownership rate, has successed to stop the rising car ownership and to increase the share of public transit use thanks to high frequencies and reliable services with easing transfers between routes. The key issue in its success in encouraging public transit use despite the high level of car ownership and economic wealth is commonly ascribed as the economical densities of patronage allowing trams to cross-subsidize busses. So, the average maximum route distances of bus lines are quite low and equal to drive distance of the same route indicating that they are directly connected to the rail stations without rambling in neighborhoods to maximize the passenger number and profit obtained. The initial attempts of integrated and seamless travel regardless of the modes to be used in Melbourne , where population density (495 per/km^2) and share of public transit use (16%) is at a much more lower level with a really high rate of car ownership (558 ‰), are also strong enough to change the trend of ever-increasing rate of car ownership and share of automobile use in urban trips. Although the

maximum route distances of the sample feeder bus lines are quite short similar to the case in Zürich, their ratio to drive distances of the same routes are 1,2 which means the busses have still operates with a profit maximization concern in Melbourne.

Departing from the knowledge obtained from literature review and investigating the world cases, the case study within the current research has assesed the performance of integrated multimodal transit system of Kızılay-Çayyolu metro line and feeder bus lines in providing accessibility from the CBD –Kızılay- to urban activity locations along the transit corridor. The performance of an integrated multi-modal transit system is ascribed to how it affects the accessibility of parts of the city or the ease of accessing to activity locations in other words. Therefore, the time-geographic approach is adopted for discovering the geography that is accessible from the city center by means of Kızılay-Koru metro line and bus lines integrated to it. The precondition for accessibility in this context is defined through the upper limit of time budget, verified data of which is not available in hand. Thus, the assumed travel time budget within this study is based on the constant travel time theory. In this regard, the pratical methods suggested by time-geography approach are applied in this study. Essentially, this study follows a methodology combining the space-time path and adjusted impedance matrix within time-geographic appraoch for discovering accessible areas under the assumption of constant travel time budget. The constant travel time theory argues that the daily mean travel time budget is constant over space and time and is approximately one hour. However, the accessible areas have determined under the assumptions of three alternative value for constant travel time budget of 30-45-60 minutes to ensure flexibility in travel time budget for Ankara metropolitan area as it is not approved to be strictly equals one hour. The temporal variability in geographic distribution of accessible areas is inspected through schedule-based determination of travel time costs for peak and off-peak hours in a weekday and in Sunday. GIS-based tools of data management, spatial analysis and visualisation are employed throughout the study.

The coverage of geography over which the integration facilities are provided which is the first sub-question of research is determined by mapping the metro line and its

stations, and all the stops on bus routes that are linked to rail stations on the transit corridor. It covers a large area of urban settlement especially in the western development axises, but not necessarily equals to the area accessible from the CBD –Kızılay- by means of the integrated transit system of Kızılay-Çayyolu metro line and its feeder bus lines in the given contraints.

The second sub-question seeking how the accessible geography is shaped in the given travel time budgets is lightened by the first part of the case study determining the accessible geography based on the relation between the assumed constant travel time budget and total travel time cost allocated on each segments of a journey from CBD to the arrival bus stops as final destinations. Basically, the locational data of stations and stops, schedule information, travel time, and walking time for estimating the travel time allocation and total travel time cost are obtained from EGO urban transit infromation system and Google transit as the two basic data sources freely available. The arrival stops on the feeder bus lines departing from the metro stations and serve to the settlement areas the travel time cost of accessing to which is smaller than the available travel time budget are presents the bus stops that are accessible under the given travel time budget. The overall area covered by the maximum walking distance buffers represents the geography that is accessible from CBD by means of the metro line and its feeder bus lines under the given travel time constraint as illustrated by maps.

Regarding the third sub-question which searches how the accessible geography is varied in peak and off-peak hours in weekdays and off-peak hours, it is explored that the accessible geography varies in peak and off-peak hours in weekdays and Sundays based on the system facilities of multimodal integrated transit. The geography that is accessible from the city center by means of Kızılay-Çayyolu metro line and its feeder bus lines is wider in peak hours in weekdays than the others since both the metro and bus services are provided more frequently which decrases the waiting time within a journey. The schedule of the transit systems is therefore the crucial factor determining the changes in accessible geography in varying days and times. The spatial pattern of accessible geography shrinks as going from the center towards the

outer stations as the travel time to reach the outer stations increases and remaining time for travelling to final destinations by feeder buses falls. In peak hours in weekdays –when the public transportation services are offered by the highest standards- within 60 minutes which is the highest travel time budget, 21% of the stops linked to Bilkent station is inaccessible. This rate rises to 29% in Beytepe, to 78% in Ümitköy, and to 64% in Koru station. Moreover, the rates of inaccessible stops in 60 minutes travel time are even higher in off-peak hours in weekdays and Sundays than in peak in weekdays.

The fourth question seeking how the travel time is allocated on parts of a journey from the city center through the integrated multimodal transit system is answered by analysing the average time allocated for in-train and in-bus travels as well as waiting times, eggres times, and walking times as parts of a journey from city center to arrival bus stops as final destinations. Accordingly, it is determined that less than half of the total travel time of journeys by means of the integrated system of metro line and feeder busses within the area accessible in a 60 minutes travel time belong to the in-train travels. It is also remarkable that the share of waiting time for bus at interchange station ranges between 10%-30% of total travel time. The high share of waiting time when transferring from the primary mode –metro- to the feeder mode –bus lines- could be a strong reason for passengers to prefer travelling options which do not necessiate a transfer. It is considered as an operational weakness that the waiting time to transfer from metro to the feeder lines which provide access from metro to the final destinations is almost the same as time cost of travelling in the primary mode. The difference in average in-bus travel time of journeys to all the linked stops and to those in 60 minutes of access area is highest in the journeys through Bilkent, Ümitköy, and Koru stations. This means that the journeys through Bilkent, Ümitköy, and Koru stations are significantly limited by the travel time budget of 60 minutes while it does not constraint the jourmeys through Söğütözü, MTA, and Danıştay stations. It is such that the share of in-bus travel time in the journeys from these station to all the arrival stops goes much more higher than the share of in-train travel times.

The fifth sub-question seeking how the accessible geography is constrained in relation to travel time allocation is answered through space-time paths of observed journeys from city center to arrival stops of feeder bus lines which have the highest passenger volume from each stations. The space-time paths showing the segments of a journey based on changes in space and travel time allocation have indicated that the shorther the time spent on bus waiting, the higher the remaining time for moving forward on space, which means the larger accessible geography under the given time budget. The travel time budget of 30 minute ends all the journeys on the sample lines before reaching the last arrival stop. It is also concluded that the size of inaccessible area is not only a result of the path segment of in-bus travel, but also a result of time spent in the earlier segments such as waiting, walking and in-train travel. Hence, there are journeys end while waiting for the bus or before reaching the transfer stop. The size of the settlement unit that is serviced by the feeder bus lines and the length of these lines are also factors determining the accessible geography around each stations. But the extensions of path segments from the last arrival stops forward present the time and space at which the accessible area would be limited by the time budget as the single factor in the case of feeder bus lines are in infinite lengths.

The basic findings from the case study have given birth to some discussions on recommendations for both improving the multimodal integration in transit systems and the geography it provides access from the city center, especially for the case of Kızılay-Çayyolu metro line and the feeder bus lines along the transit corridor. These recommendations are basically related to transit system infrastructure, operating & management policies, and urban development & planning, covering both the integration facilities and urban development strategies so that the accessible geography could serve the residents efficiently.

Regarding the transit system infrastructure, the Kızılay-Çayyolu metro line generally goes along the edges of settlement areas which makes it difficult to be efficiently integrated to bus lines. The stations from Söğütözü to Çayyolu are on the Eskişehir Road, the very limited permeability of which causes metro stations to have a difficult access from nearby areas. It would not be tha case if the metro line were passed

within the settlement areas where the stations could provide direct access to urban uses and the the distance to be overcomed by the feeder bus lines could be almost half of the current lines. However, this issue remains as only a criticism since it is known that the metro infrastructure is not flexible to be revised. So the recommendations for improving the performance of the existing metro line together with the feeder bus routes have gained importance. Secondly, it is recommended that an extension of the metro line is not needed enable larger accessible geography. It is not already possible to access the whole service area of existing metro line from the CBD within the assumed constant travel time budgets. Therefore, extending the metro line under a single operating system will neither contribute positively to the accessible geography nor will result in an efficiently integrated multimodal transit system. Thirdly, alternative transit services between the settlement areas at the south (Alacaatlı, Dodurga, Beytepe) and the CBD (Kızılay) is strongly recommended because they are out of the accessible area even in a 60 minutes travel time in peak in weakdays. Besides, the busses are operated in long distances from metro stations to these settlement areas causing both higher cost of bus operation and occupying the limited bus fleet longer. The suggested alternative transit route could either be a metro line or bus line which is not possible to be decided in the scope of current study.

The operating & management policies are considered as the primary interventions to improve the multimodal integration in transit system of Kızılay-Çayyolu metro line and the feeder bus lines. In order to provide access to a wider geography and higher number of citizens in a shorter time, it is necessitated to increase the overall operating speed of the system and to diminish the overall travel time. The in-train travel time, in-bus travel time, and bus waiting time are suggested to be primarily reduced. The main suggestion for reducing the in-train travel time is operating express metro services that only stops at the stations with significant passenger density at peak hours. So the access time to stations serving to the remote settlement areas (Koru-Ümitköy-Beytepe) which are largely outside the accessible area by train will be shortened. The time saved from the in-train travel will inevitably added to the travel

time budget of travelling from the stations to the final destinations by feeder buses. Secondly, it is strongly recommended to reduce the bus waiting time when transferring from metro to feeder busses. Since the intervals of feeder bus lines range from 4 mins to 60 mins where the metro –the primary mode- serves with a 4 minutes interval, the average bus waiting time at transfer stations approximatly takes the 30 % of the total travel time. So the accessible geography is supposed to be expanded by the rate of 15% if the frequency of busses is doubled. Similarly, the average in-bus travel time is needed to be reduced as the third recommendation for operating policies. The crucial intervention for achieving shorther in-bus travel time is cutting of the feeder bus routes in parts. In the case study of Kızılay-Çayyolu metro line and its integration with the feeder bus lines, the busses meander within the entire settlement units making the journey that can be completed in shorter time by driving much more longer. For this reason, shortening the bus lines will significantly shorten the in-bus travel time and will allow the frequency of trips to be increased as the time the bus fleet is in service will be shortened. The settlement areas that are not covered by the shorter bus lines are recommended to be serviced by the express bus lines. The last suggestion regarding the operating system is to integrate the operation of private public transit busses that serve along the alternative routes to the Kızılay-Çayyolu metro line to the feeder bus lines and to the metro.

In addition to the transportation infrastructure and operating system, suggestions from the perspective of urban development and planning could be made departing from the findings on accessible geography within a constant travel time budget created by a multimodal integrated transit system between the CBD and settlement areas along which the infrastructure is provided. That is, the urban development and planning interventions could also improve the integrted service quality and the effectivity of the accessible geography in addition to the recommendations mentioned above. First of all, altough the population density along the transit corridor is known to be an average of 50-100 per/ha, it is much lower especially in settlements at the south around Koru, Ümitköy and Beytepe stations. It causes the feeder bus lines to travel around large areas to serve a particular amount of urban

population. The main reason for the current situation is that the urban sprawl from the central area along the soutwestern axis. Although the integrated planning works both for urban development urban transportation in 1990s aimed to control the urban sprawl and to enable transit oriented urban development along the corridor in parallel to the planned Kızılay-Çayyolu metro line, it could not be controlled as expected. It has taken the form of a low-density urban development far from being transit oriented but automobile dependent which is also far from the CBD but has no hierarchical pattern of sub-centers. For this reason, the first recommendation in terms of urban development is the population intensification along the road network suitable for the servicing of bus routes rather than further sprawl towards the inaccessible areas. In addition to population intensification, the active urban land uses are also needed to be planned along these routes so that they could be accessed in a shorter time by the local residents. Secondly, it is recommended to plan development of sub-centers or an alternative CBD along the southwestern development corridor in the single-nucleus Ankara metropolitan area, departing from the fact that large residential areas cannot be accessed from the existing CBD in the given travel time budgets revealed by this study. Thus, creating a geography access from which to the CBD would be possible 30, 45 or 60 minutes is supposed to enable population intensification and corridor type of development strategies to be successfull. The last recommendation based on the current study is to integrate both the planing and implementation of the urban development and transportation projects. As the metro line planned in parallel with the urban development was put into service with a delay of 15 years from the planned date, urban development took place in a form independent of public transportation in this time period, which is the main cause of the urban transportation problems that the southwestern development corridor has been facing until today. Moreover, the fact that the metro line is passed through the edges rather than within the already built residential areas, the metro stations are not located where the intense urban land-uses are densified, the feeder bus lines ramble in low-density residential areas to reach a large number of passengers are some of the results of the urban development and transportation

decisions have been made independently from each others. Therefore, the integration of urban development and urban transportation planning, apart from all other suggestions, is an important recommendation that this study advocates especially for the metropolitan area of Ankara.

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